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PHYSIOGRAPHY

AN INTRODUCTION TO THE STUDY OF NATURE

BY

T. H. HUXLEY

REVISED AND PARTLY REWRITTEN BY

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WITH 301 ILLUSTRATIONS

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PREFACE

THE responsibility of revising a work by Huxley would not rest lightly upon the mind of anyone familiar with the style of that great master of English prose. In the present case, the invitation to prepare a new edition of a work which has long been accepted as a standard of scientific exposition aroused a lively consciousness of the difficulty of the task; and duty only prevailed over diffidence because of a belief that the sphere of influence of the book might be widened. Fortified by Huxley's counsel to "Do what you can to do what you ought, and leave hoping and fearing alone," an attempt has been made to increase the attractiveness of the book without sacrificing its scientific character, by taking advantage of the greater possibilities of book illustration that exist now in comparison with what were available when the original work was published.

Of the three hundred illustrations in the present volume, only six have appeared in the text of the old editions, the remainder being reproductions from new drawings or photographs. Many of these prints have been generously provided by men of science whose work is freely given when it is to be used for the extension of natural knowledge; other photographs have been taken expressly for this book, and a large number have been reproduced from pictures by professional photographers. To those who have thus assisted in elucidating the text, either with or without recompense, adequate acknowledgment cannot here be expressed; but it is pleasing to remember that in most cases the picture is regarded as a tribute to Huxley's memory from the photographer whose name appears under it.

Fortunately for the progress of the revision of the text and the promise of its ultimate success, valuable help was forthcoming in directions in which it was most needed. Dr. F. J. Allen, whose intellectual catholicity and scientific knowledge are familiar to many men of science, has revised a large part of the book; and the chapter on geological structure and history is due almost entirely to him. It is easy for one man to show interest in the work of another, but the close attention and substantial aid given by Dr. Allen are as rare as they are gratifying to remember. Mr. Hugh Richardson, of Bootham School, has been most fertile in suggestions—indeed, it was largely due to him that the revision was undertaken—and as he has used the volume in his classes as an introduction to the study of science, the experience thus gained has been of great service. The additional particulars on maps and map-making were drafted by Mr. Richardson, and the whole book has had the benefit of his sympathetic interest. What the present volume would have been without the constant attachment which has been shown by these and other friends it is perhaps best not to inquire. Only a book by Huxley could stimulate such regard into action.

As to the character of the revision, a few words of explanation are necessary, if only to justify what has been done. The original volume was based upon a course of lectures on the Thames and its basin; and after showing how this local text could be made the subject of a comprehensive analysis, Huxley remarked that an intelligent teacher would have "no difficulty in making use of the river and river basin of the district in which his own school is situated for the same purpose." To facilitate the use of the book in this way, the point of view has been transferred from the Thames to river basins in general, and the references to the Thames have only been retained when they seemed essential to the descriptive text. It is hoped that this change of aspect will not render the book less interesting to students in the south of England, and will increase its opportunities in schools far removed from the neighbourhood of the Thames.

The new outlook has, of course, not necessitated any departure from the "incidental" method of regarding nature now adopted in science teaching. Leaders of the "Nature Study" movement agree that the method of approach advocated by Huxley in his "Introduction to the Study of Nature" is the best one to follow if scientific thought is to be developed. The words in which this principle are expressed are here given; and they should form one of the articles of belief of every educational philosopher:

"The teacher who wishes to lead his pupil to form a clear mental picture of the order which pervades the multiform and endlessly shifting phenomena of nature, should commence with the familiar facts of the scholar's daily experience; and from the firm ground of such experience, he should lead the beginner, step by step, to remoter objects and to the less readily comprehensible relations of things. In short, the knowledge of the child should, of set purpose, be made to grow, in the same manner as that of the human race has spontaneously grown."

To put this cardinal principle of scientific education into practice, it is essential that the pupils should make precise observations of natural objects and phenomena; and upon the personal experience thus gained should be based inquiries as to the relation between consequence and cause. It was originally intended to supplement each chapter with a set of simple subjects for observation and measurement, which could be undertaken out of doors or in school; but the size of the book would have been increased to such an extent by these instructions for practical work, that it was reluctantly decided to omit them. Fortunately, the authors of another volume[1] found it possible to make use of this material; so that teachers and students now have at their disposal a suitable practical course to accompany the descriptive text of the present book.

R. A. GREGORY.

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[1] *An Introduction to Practical Geography*, Sections I—IV, by A. T. Simmons, B.Sc., and Hugh Richardson, M.A. Price 3*s*. 6*d*. Published separately, Section I. Maps, Section II. The Globe, Section III. Climate, 1*s*. each. (Macmillan and Co., Ltd., 1906).

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PHYSIOGRAPHY

CHAPTER I

MAPS AND MAP READING

Meaning of map.—If a person in a balloon at a great height over any part of the earth's surface sketched in outline what he saw directly below, his sketch on a flat surface like this page would be called a **map.** When the portion of country thus delineated is but small, the sketch is generally termed a **plan**; and if the area depicted consist chiefly of water instead of land, it is called a **chart.** Hence

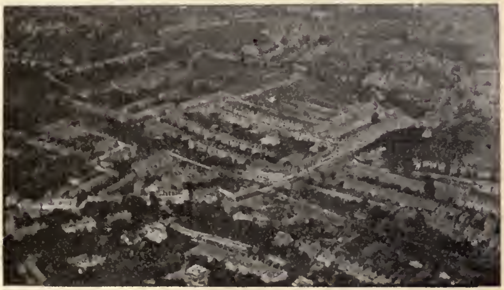

FIG. 1.—View from a balloon. Reproduced by kind permission from a photograph by the Rev. J. M. Bacon.

we commonly speak of the plan of an estate, the map of a country, the chart of an ocean. A map then, is simply an outline-sketch of a portion of the earth's surface, as would be seen from a balloon passing at a great height directly over the country (Figs. 1 and 2). It is the common practice to draw maps in such a position that the north is towards the top, and the south towards the bottom; while the east lies on the right hand of the person who looks at the map, and the west lies on his left hand.

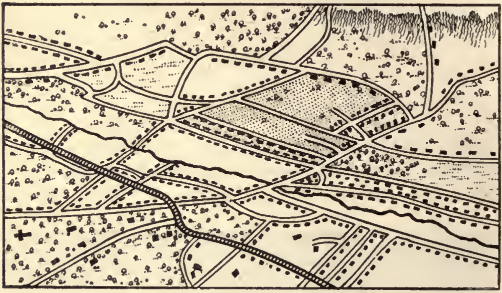

FIG. 2.—Sketch map representing the view photographed in Fig. 1.

Cardinal points.—These terms—north and south, east and west—are terms which have a meaning quite independent of local circumstances, and indicate definite directions which can be determined in any part of the world and at all times. It is desirable to explain how these cardinal points may be determined.

Of the four points, the south is perhaps the most easily found, at least on a sunshiny day. Every morning the sun appears to rise slowly in the sky, and mounts to its greatest height at noon. At the instant of reaching its greatest height, or in other words at **apparent noon,** the sun is precisely in the south. If, then, you place yourself in such a position as to have the sun shining full in your face at that particular time, you must be facing south; and you will consequently have your back to the north, your right hand towards the west, and your left towards the east (Fig. 3).

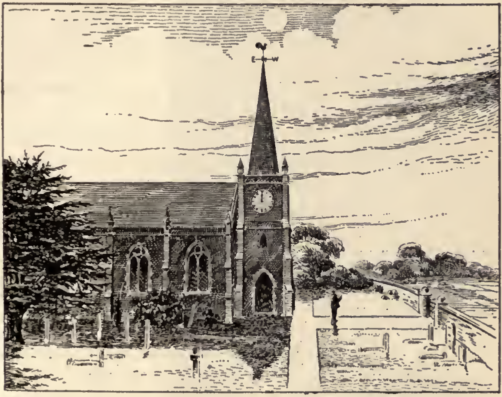

FIG. 3.—The sun is due south when the shadows of upright objects are shortest for the day. This occurs about twelve o'clock noon.

Determination of meridian line by sun.—As true noon does not always coincide with 12 o'clock, as indicated by an ordinary timekeeper, it is necessary to explain how it may be determined. Observe, at different hours of the day, the length and direction of the shadow of an upright post or flagstaff cast by the sun (Fig. 4). When the sun is rising in the sky, the shadow is thrown towards the west; and when the sun is going down, it is thrown towards the east; at noon, however, it inclines neither to the east nor to the west, but falls exactly in a north-and-south line; and, moreover, the shadow is then *shorter* than at any other time. If, therefore, you observe when the shadow is shortest, that time will be exactly noon. The line indicated by the shadow at noon is known as the **meridian line** or **mid-day line.** That end of the noon shadow-line which is towards the sun points to the south, and the opposite end to the north.

FIG. 4.—A line drawn mid-way between the directions of shadows of equal length of a fixed object before and after noon is due north and south.

Instead of observing the shadow of a vertical post or flagstaff, a lady's hat-pin may be fixed upright in a board lying flat on the ground or on the top of a wall. The change in length of the shadow of the pin during the day can thus be easily seen. It is not easy, however, by merely looking at the shadow of a post or pin, to say when it is exactly reduced to its shortest length. It is well, therefore, to observe the shadow at some time in the forenoon and mark its length, and then in the afternoon to observe the shadow again, when it has reached exactly the same length. The afternoon shadow will then be just as much on one side of the meridian line as the forenoon shadow was on the other side. The mid-day line, or the line which runs due north and south, will therefore be exactly half-way between the two shadows.

The north-star.—But it is by no means necessary to have daylight in order to discover the direction of the cardinal points. If you look up into the heavens on a clear starry night, you will have no difficulty, in this part of the world, in finding that curious group of seven bright stars, known as Charles's Wain, or The Plough (Fig. 5). A line drawn through two of these stars, known as the **Pointers,** will, if prolonged to about five times its length, pass very close to the famous **Pole-star** or **North-star.**[1] On a clear night, all the groups of stars appear to move slowly round a certain motionless point in the sky, which is the north pole of the heavens. That point of the heavens which is directly above the north pole of the earth is the celestial north pole. Hence, if explorers could reach the north pole, they would find the pole-star almost directly overhead. It must be remembered, however, that the pole-star is not

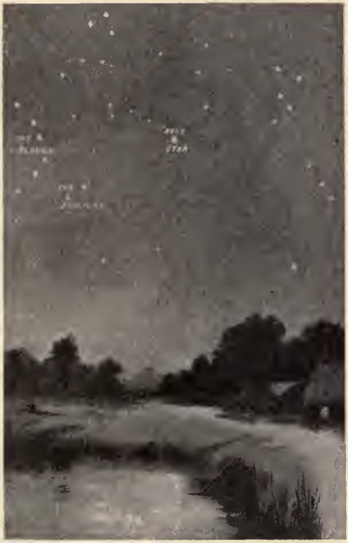

FIG. 5.—The north point can be found at night by turning toward the Pole-star or North-star.

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[1] The word "pole," which, in common English, signifies a long straight stick, is used in astronomy and geography in the sense of the Greek πόλος (*polos*), a pivot on which everything turns.

exactly at the north pole of the heavens, although very near to it. By observing the position of the pole-star, the north can be determined on a clear night as readily as the south may be determined by the sun at noon.

The magnetic compass.—If, however, the sun is beclouded, so that the heavenly bodies are not visible, there is yet another easy means of finding the direction of the cardinal points. Let a thin bar of steel, or even a needle, be nicely balanced upon a pivot (Fig. 6) or suspended by a thread, or floated upon a cork in water, so that it can turn freely in all directions horizontally; it will be found that the bar may be brought to rest in any desired position. If, however, the bar be rubbed with a magnet, a peculiar change is wrought in the steel, and it then no longer exhibits this indifference to direction, but, when left free, always takes up a definite position, one end pointing in a northerly and the other in a southerly direction. This property is taken advantage of in constructing the mariner's compass. About two hundred and fifty years ago the compass pointed exactly north and south in London; but from the year 1660, or thereabouts, the end which tends northwards, and is therefore commonly called the *north pole* of the needle, began to turn a little to the west; this variation from true north continued

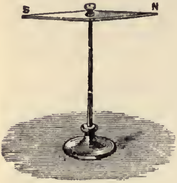

FIG. 6.—Compass needle balanced on a pointed pivot.

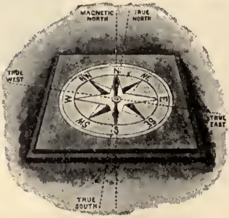

FIG. 7.—In England the north end of a compass needle points slightly to the west of true north.

until the year 1816, when it reached its greatest divergence, and since that time it has been steadily creeping back. The divergence of the position of the magnetic needle from the true north-and-south line is called its **declination,** or, by nautical men, its **variation.** In 1816 the declination amounted to nearly 25°, but in 1904 it was little more than 16° in London; that is to say, the end or pole of the needle which turns in a northerly direction, instead of pointing due north at London, points about 16° to the west of true north. This declination is shown in Fig. 7. The declination at any epoch differs at different parts of the earth, but knowing its value it is easy to make the proper allowance and thus find the true points of the compass (Fig 8).

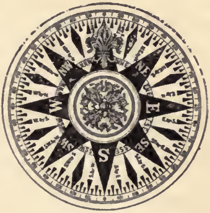

Fig. 8.—A compass card, showing the points of the compass.

Scales of maps.—A map, however, does something more than show simply *direction*; it gives us, in addition, some notion of *size*. A map, as we have seen, is a kind of picture, and the size of this picture must bear a certain ratio to the size of the object represented. This ratio is called the **scale** of the map. If a map is said to have a scale of one inch to the mile, it is simply meant that a mile measured along the ground is represented by an inch measured on the map; or a square mile of country is represented by a square inch on the map, and so on. Most of the wonderfully accurate maps of the Ordnance Survey of the United Kingdom are constructed on this scale of one inch to the mile. In other words, in the map of a given district, the distance between any two points is $\frac{1}{63360}$th of the actual distance, since there are 63,360 inches in one statute mile. The fraction which denotes the ratio of the two distances is sometimes termed the **representative fraction.** Maps on a scale much greater than this are constructed. The Ordnance Survey, for example, issues county maps on a scale of six inches to a mile, the representative fraction being here $\frac{1}{10560}$ (Fig. 9). Parish maps are also issued on a scale of $\frac{1}{2500}$ of the actual length on the ground, so that one square inch on these plans approximately represents one acre.

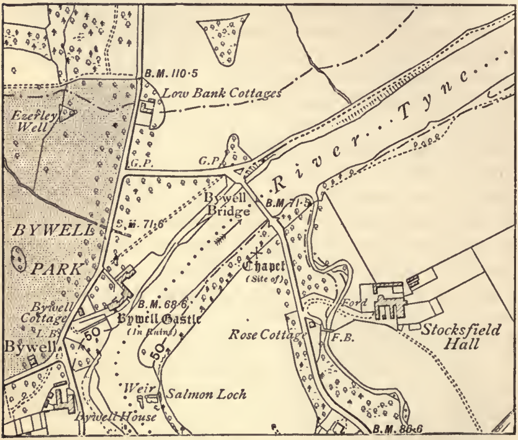

FIG. 9.—Part of a 6-inch Ordnance Survey map. From sheet Northumberland, XCV, S.E. Bywell and Stokesfield.

Representation of differences of slope by shading.—In most maps, except those on an extremely small scale, an attempt is made to show something of the general features of the ground, especially whether the country is hilly or not. This is commonly effected by a system of hill-shading, such as that represented in Fig. 10. If the ground is steep, the lines, or **hachures**, are drawn thick and close together, so that the steep places become dark; if the ground is tolerably level, the lines are thinner and farther apart, and the general appearance of the map is consequently lighter.

A hachured or shaded map, hung on a wall at some distance from the eye, gives a good general impression of the lie of the land. The white portions are either nearly level mountain tops, shelves on the hill-side, or flat valley bottoms. The very dark places are crags, the paler shades gentle slopes. Bringing the map nearer to the eye, the stream lines are seen, towards which the hills must slope in opposite directions.

Such a system of shading, however, though effective by its combination of light and shade, shows in most cases merely that one part of the country is steeper or flatter than another, without enabling us to judge how much higher or how much lower. But in very accurate maps, such as those employed for military purposes, a definite scale of shade is often used.

Contour-lines.—Another and entirely different method of representing difference of level is by drawing curved lines connecting points having the same heights above sea-level. In Fig. 11, for instance, it will be observed that, instead of hill-shading, a number of curved lines have been traced over the map, giving it a peculiar character. These curves are called **contour-lines,** and their meaning is extremely simple. Suppose the valley of a river were flooded with water, and that this water could be dammed in or prevented from escaping, by a wall built across the mouth of the valley. If sufficient water covered the ground to stand 100 feet above the level of the sea, the surface of the water would form a plane, and its margin would trace a line, winding round every hill and up every valley, at a height of exactly 100 feet. Such a curve would be the 100-*feet contour-line.* Another curve, drawn at a height of 200 feet above the sea-level, and therefore representing the margin of a body of water standing in the river valley 200 feet above the sea would be the 200-feet contour. In like manner, a succession of these contour-lines may be drawn, each at a distance of 100 feet from the next one below, just as though the flood rose in the valley and stopped at every 100 feet to leave its mark around its margin. It is evident that a system of such lines conveys a more exact idea of the character of the ground than can be obtained from ordinary hill-shading.

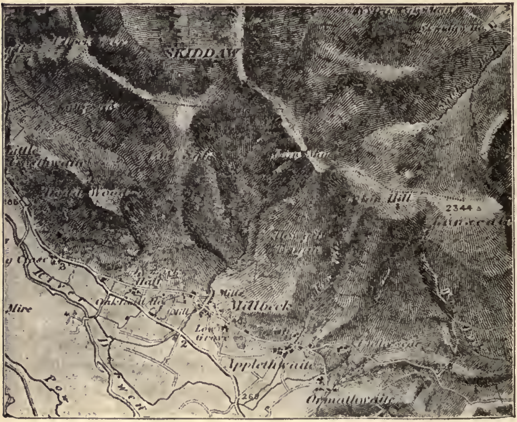

FIG. 10.—Part of a 1-inch Ordnance Survey map with hachures.

Visible contours.—Though contours are only imaginary lines, it is often possible to obtain a general view of their direction by noticing well-marked levels in a country scene. Thus, in a mountain district you may see level lines formed by the edge of a lake, by a road or a railway, by a wall marking the margin of cultivation and the edge of the fell; and, higher still, are level lines formed by sheep tracks, by the snow line on an autumn morning, and by the edge of the mist which shrouds the summit (Fig. 13).

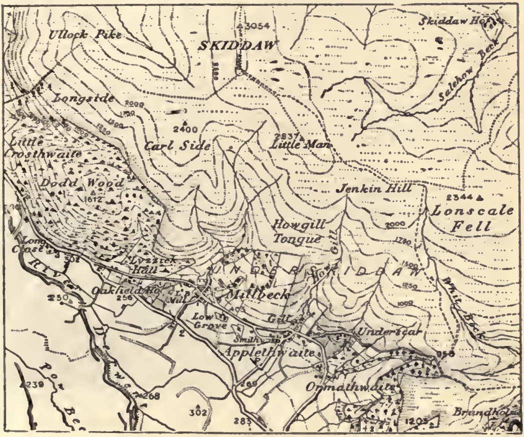

Fig. 11.—Part of a 1-inch Ordnance Survey map with contours.

These horizontal lines could be represented on a map by contours. Suppose further that the lines happen to be just 100 feet apart in altitude from the lake 500 feet above the sea-level to the cairn at 1,500 feet. Where the lines are mapped close together, the slope must be steep; where far apart, the slope is gentle. Everywhere the slope is at right angles to the lines, hence the streams intersect the lines at right angles or nearly so. Fig. 13 shows these lines represented as contours, and from such a map a good mental picture of the shape of the country represented may be obtained.

Details of contour-lines.—Contours are generally complete rings or closed curves. If the ends of a contour are not connected within the map some connection must be imagined outside. Contours never cross each other, and they are everywhere at right angles to hachures.

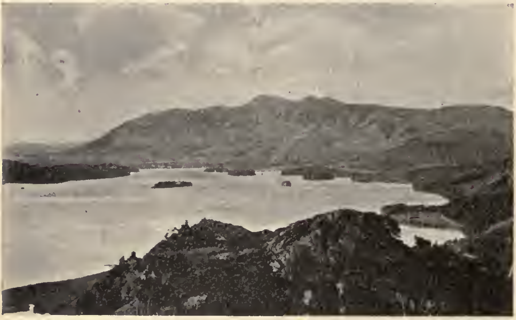

Photo. *Alfred Pettitt, Keswick.*

FIG. 12.—View of Derwentwater and Skiddaw. The hills are represented upon the maps in Figs. 10 and 11.

The British Ordnance Survey maps are published in two editions, one hachured, the other contoured; and for some districts maps are issued in colour, with hachures in brown and contours upon the same sheet. There are also maps, copied from the Ordnance, on which the contours are made easier to understand by colouring the zones between them, so that all ground below 200 feet is green, or ground between 500 and 1,000 brown.

Some practice is necessary before the eye can readily follow the contour lines on an uncoloured survey map. Where footpath and contour coincide—and footpaths are apt to follow level lines on hill-sides—only the footpath is shown. Following a contour line is like paperchasing, and some of the same principles apply; for instance, if a contour enters a wood and is lost there, it will probably be found again emerging on the farther side of the wood.

A contoured map does not give the same general impression of the shape of the ground that a hachured map affords.

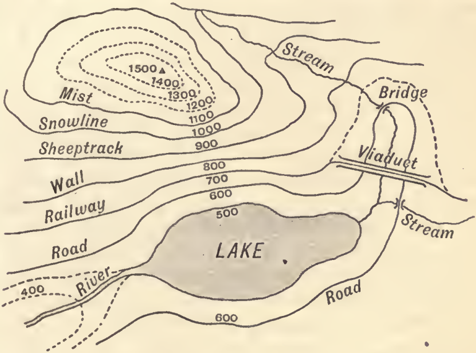

FIG. 13.—Contours. Showing natural and imaginary lines of equal altitude above sea level.

But the contoured map is admirable for finding the way in a long walk over rolling uninhabited moorland, or through drifting mist, where there are no roads, houses, or signposts, and the traveller must identify his position by the shape of the ground and by estimating the distance travelled from his last known point.

The steepness of the slope is proportional to the number of contour lines; and the direction of the slope is at right angles to them. A level path is roughly parallel to the contours; all sloping paths are aslant across them. Parallel contours at equal distances indicate an even slope, unless the numbers on them are at unequal intervals, as 800, 900, 1,000, 1,250, 1,500.

V-shaped lines fitted inside each other may mean either a valley or a ridge; the position of the stream line will generally enable one to be distinguished from the other. Isolated rings indicate hillocks; when the valley is filled with white mist these stand out as islands.

Map sections.—From a contoured map it is easy to obtain a **section** across any line of country, for instance, along the line A B drawn on the map represented at the top of Fig. 14. A sheet of paper ruled in squares is laid over the lower part of the map. The intersections of A B with the contour lines are marked off along the top edge of the squared paper. The horizontal lines on the left are numbered from 500 to 1,100 to agree with the contours. Vertical lines are then traced down from each contour as seen in the map to the same contour in section, the resulting point being marked with a cross. On joining these crosses the required section is obtained. It is obvious, however, that the vertical scale has been greatly exaggerated as compared with the horizontal. It is a common practice in constructing such a diagram as this to draw the heights to a scale many times greater than that used for the lengths. Without such exaggeration, the surface of the country would appear in a small diagram to be almost flat. There is clearly no harm in the practice of drawing diagrams on this principle, provided that the exaggeration of one dimension is always borne in mind. Great misconception, however, constantly arises from mistaking these intentionally distorted diagrams for true figures.

Landscape.—A diagram such as that in Fig. 14 is not only a section, but also shows the general shape of the land as seen from a considerable distance. On reducing all the vertical distances by the same amount the appearance of the hill in the landscape at the bottom of the figure is obtained. The problem of making a really accurate picture from a map of a mountain group is complicated by the perspective enlargement of hillocks in the foreground and diminution of mountains behind. The altitude of the spectator and the curvature of the earth must also be considered. Just as in drawing sections the vertical scale is often exaggerated, so a landscape sketch of distant mountains is apt to show the serrations on the sky-line more pronounced than a photograph would justify.

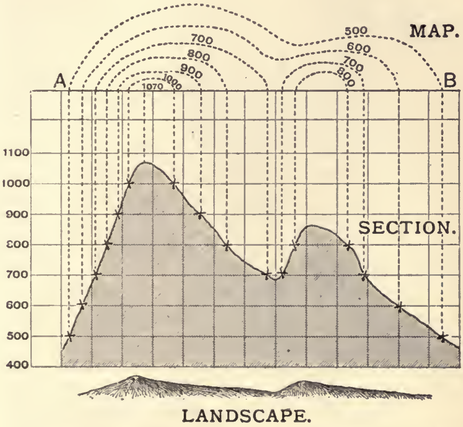

FIG. 14.—Showing how to construct a section from a contoured map, and also how the form of the section compares with the real landscape.

Roads and contours.—An English railway line is seldom steeper than 1 in 50, and is therefore almost a contour, although this contour is often the result of a cutting or embankment. The old Roman roads were made straight from point to point with little attempt to consider the slopes; and most of our country roads are a compromise between the lines of shortest distance and least inclination. In modern road-making an attempt is made to keep the slope of the road uniform, and on this account equal lengths of road lie between adjacent contours. If the ground is naturally very steep the road is made in a zigzag form to give it the required length. In choosing a line of ascent for climbing a hill it is best not to follow a straight line, but to find a route which lies where the contours are far apart.

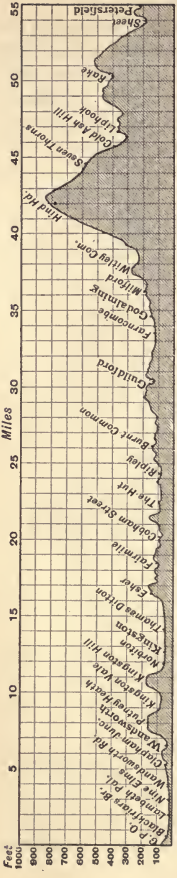

FIG. 15.—Graphic representation of inclination of road from London to Petersfield. Horizontal scale, 1 inch to 10 miles. Vertical scale, 1 inch to 1,000 feet.

Slope or gradient.—A gentle slope which a pedestrian would scarcely notice, is detected at once when cycling, and as the convenience of roads for cycling depends on gradients more than on directness, contour road-books are used in which the ups and downs of the road are mapped but turns to left and right neglected (Fig. 15). These, however, are not exactly sections, because they do not follow straight lines on the map.

Simple method of map making.—The preparation of exact maps requires instruments of great perfection, skilled observers, able mathematicians, and trained draughtsmen. But a sketch map of a small area may be obtained with very simple apparatus. A drawing board having a compass upon it is slung over the shoulder by a strap or loop of thick cord, so as to form a portable **plane table**, on which paper can be pinned and drawing done whilst standing. The map is begun by drawing upon the paper a line which is to be magnetic north and south. The board is put into position so that this line is in the real magnetic meridian, and as the surveyor walks about he continually brings the board back to its bearings. The map is made out of doors; and lines are drawn upon the paper as soon as the distances are measured, without writing down their lengths in figures. The measuring is done by pacing, the length of a pace having been previously determined by counting the number of steps taken to traverse a measured distance, or the distance travelled in, say, a hundred steps. With a little practice, the pacing becomes steady, and the length of a step practically constant.

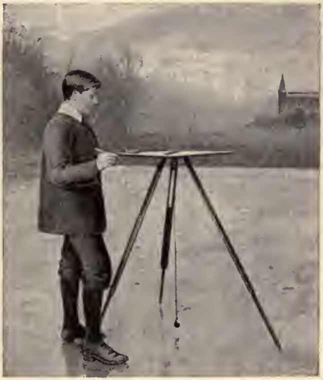

FIG. 16.—A plane-table for surveying. (From a photograph.)

Angles as well as lengths may be drawn directly on the board, without being measured in degrees. Right angles are easily recognised and drawn. To determine and set down other angles, the surveyor stands at one end of the line to be measured and turns the drawing board until the fundamental north and south line coincides with the direction of the compass needle. He then points a ruler to the other end of the required line and takes a sight along it until it lies in the right direction. When this position has been obtained, the line can be plotted on the drawing paper on the board.

For greater accuracy in this simple method of making maps, two surveyors should work together, and a strong tripod stand, such as is used to support a photographic camera, should support the board (Fig. 16). Distances should be measured by a tape line or chain instead of by pacing, and the ruler used to point to the various directions should be furnished with a sight at each end. A spirit level will show when the table is horizontal, or a steel bicycle ball may be used for the same purpose.

This method of making maps direct in the field is termed **plane table survey,** from the flat board used. It provides a simple and rapid means of surveying comparatively small areas, and is largely used by Government surveyors in India, though, of course, more precise means of sighting and levelling are employed than are possible with the simple apparatus here described.

CHAPTER II

SPRINGS AND RIVERS

Permeable and impermeable rocks.—Mark what happens when a heavy shower of rain falls upon dry ground. If the ground be formed of hard and solid rock, such as granite, the rain, after wetting the surface, runs off in all directions; some finding its way to the nearest streamlet, whence it flows sooner or later into a river, and some finding lodgment in little hollows of the rock, where it collects in pools which are slowly dried up by wind and sunshine. But if the ground, instead of being hard like granite, is soft and porous like sand or chalk, the water will then sink into its substance, and may even pass out of sight before the surface of the thirsty soil is thoroughly wetted. Rocks which thus allow water to filter through them are said to be **permeable,** while those which refuse to allow the water to soak in are said to be **impermeable**: a bed of sand, for example, is permeable; a bed of clay impermeable.

It is by no means necessary, however, that a rock, in order to be porous and permeable, should be either soft like chalk, or loose like sand. Take, for instance, a sandstone, or a hard limestone: these rocks are sufficiently coherent to form durable building stones, yet porous enough, in most cases, to allow water to drain more or less freely through them. The particles of which the rock is made up are themselves impermeable, but they are so built together that little spaces, or interstices, are generally left between the individual particles, and the result is the formation of a rock which, hard as it may be, presents a texture approximately like that of a sponge. The water trickles between the particles of such a rock, and thus gradually soaks through its mass. Close in grain as the rock may appear to the eye, it is nevertheless capable, in most cases, of absorbing water; and, hence, stone when freshly taken from the quarry usually holds moisture, known to the workman as "quarry water." Even when a rock offers too close a texture to admit moisture freely, it commonly happens that it is more or less fissured; and the water which falls upon the rock then dribbles through the little cracks, and thus gains ready access to subterranean channels, much in the same way as it would if the rock were of open texture.

After a good deal of rain has fallen upon a porous rock, its pores become choked with water, and the rock at last gets saturated, like a sponge which has been dipped for a few moments into water. If more rain now fall upon the rock, it can no longer be sucked in and retained, but will flow off the damp surface, just as it would from the surface of an impermeable rock.

Arrangement of layers of rock.—Suppose a layer of a porous substance to rest upon a bed of comparatively impervious rock; it is easy enough to see what, in such circumstances, will become of the rain which falls upon the surface. Let Fig. 17 illustrate such a case. Here the light part of the ground cut away represents a permeable rock, say beds of sand, whilst the lower shaded portion indicates an impermeable rock, say a stiff clay. It is supposed, in a figure such as this, that the rocks in question have been cut through so as to expose clean-cut surfaces, and hence such diagrams, which are constantly used in writings on the structure of the earth, are termed **sections** (Figs. 17–19) Natural sections are frequently exposed in river-beds, sea-cliffs and inland valleys; whilst artificial sections are seen in wells and shafts, in mines and quarries, and especially in railway cuttings. A good general notion of the character of the rocks forming a given country may often be gained, during a railway journey, by observing the cuttings along the line.

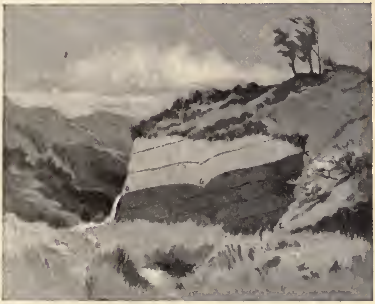

FIG. 17.—Section showing permeable upon impermeable layers of rock, and the formation of a simple spring by this arrangement.

It is clear that when rain falls upon the surface shown in Fig. 17, it will be readily absorbed, at least if the sandy rock be dry, and will gradually sink lower and lower until it reaches the bottom of the porous bed. Here it comes in contact with the surface of the clay, and, as the clay refuses to absorb the water, its downward course is arrested. Should the surface of the clay present irregularities, the water which has percolated through the sandy bed will lodge in the hollows, as at G. But when such cavities have become filled, the water with which the rock is charged will flow over them, and continue to run down in whatever direction the rocks may chance to slope.

Formation of simple springs.—It rarely happens that the successive layers of rock, or as they are technically called **strata**,[1] exposed in any given section are perfectly horizontal, or spread out with flat surfaces, like the surface of a piece of still water. Generally the beds slope or incline in a definite direction, and this slope is technically termed the **dip** (Fig. 19). If then we read in a scientific description of a given section that "the strata dip 30° S.W." it means simply that the layers of rock slant in a south-westerly direction, and make an angle of thirty degrees with a perfectly horizontal surface. Thus, in Fig. 17 the dip is shown by the general direction of the line CD, and its amount may be measured by the inclination of this line to the horizon; that is, by the angle which the line C D makes with the top or the bottom edge of the page, when these edges are horizontal. Now when the water, having percolated through the sandy rock, has reached the junction

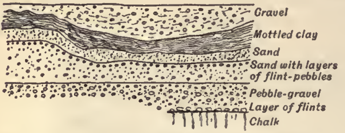

FIG. 18.—Section south of Bushey Station near Watford. (Whitaker.)

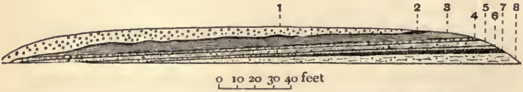

FIG. 19.—Cutting at Chislehurst Station, South Eastern Railway. (Whitaker.) 1, Pebble gravel; 2, Clay with shells; 3, Bluish-grey clay; 4, Sand with pebbles; 5, Green loam; 6, Green sand; 7, Whitish sand; 8, Buff sand.

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[1] *Stratum* (plural *strata*) from the Latin *stratum*, signifying that which is extended or spread out.

represented in section by C D, it flows down this plane in the direction of the dip, and escapes at the first outlet, as at D. Such a flow of water thrown out from a rock constitutes a **spring.** Springs of this simple character, which issue at the junction of permeable and impermeable strata, are extremely common.

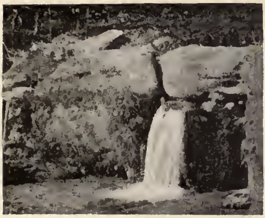

FIG. 20.—A spring formed at the junction of permeable and impermeable rock.

Horizontal and inclined strata.—From the case hitherto considered, namely, that in which a porous rock rests upon one that is not sensibly porous, it is desirable to advance to the case in which the porous material is not only supported, but is also covered, by an impermeable stratum; the pervious substance being thus inclosed between two impervious beds, one forming its floor and the other its roof. Thus, the sandy stratum B, in Fig. 21 is supported by one bed of clay, C, and covered by another, A. So long as the strata remain in the horizontal position here represented, the rain which

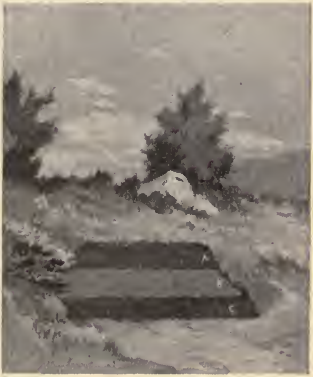

FIG. 21.—Section showing horizontal layers of rock. B, permeable; A and C, impermeable.

falls upon the surface of A is effectually prevented from reaching the porous material B, save only through any cracks which may happen to run through the upper bed. Though the material of B may be as porous as a sponge, not a drop of water can reach it, so long as the waterproof roof remains sound. But the case is extremely different when the beds are inclined, as represented in Fig. 22. Here are three beds, in the same order as those previously described, but dipping at a slight angle. The porous bed B is exposed at the surface, or as a geologist would say "crops out." Rain falling upon the ground A B C is thrown off by the two clay beds A and C, but is absorbed by the **outcrop**, or exposed surface, of the sandy stratum B. This absorbed water, whether directly falling upon B, or drained off from A, runs down in the direction of the dip until it reaches an outlet, whence it issues as a spring. If a valley should cut through the beds, and have its bottom below the water-level,

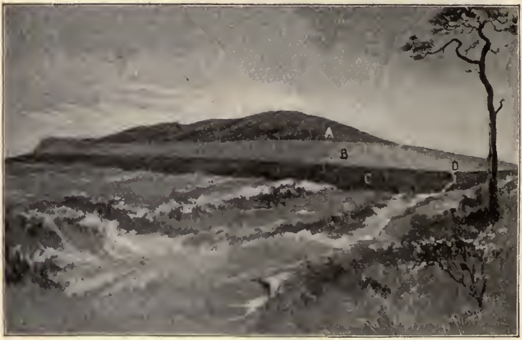

FIG. 22.—Inclined strata: A and C, impermeable; B, permeable. Rain which falls on B finds an outlet as a spring at D.

springs will be thrown out along the sides of the valley, as at D.

Fractured strata.—In following the course of a set of strata, it is no uncommon thing for the geologist to find that they come abruptly to an end, that their continuity is suddenly broken, and that one set of beds abuts upon another along a sharply-defined plane. The beds have, indeed, been fractured, and have slid one over another. Such a fracture, accompanied by displacement of the strata, constitutes what geologists call a **fault.** Thus the set of beds represented in Fig. 23 have been broken along a plane represented in section by the line D E; and, though once continuous, are now dislocated, part of each of the beds A, B, C, having been thrown down to lower positions. The drainage received by the surface of the porous stratum B, on the left of the figure, will flow down until it reaches the fault, where it will be prevented from escaping by the clay wall of the slipped layer A. If therefore a bore-hole

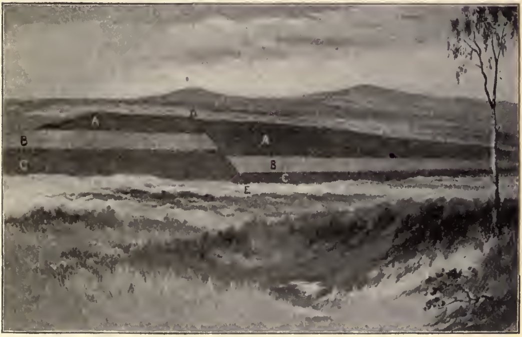

FIG. 23.—Effect of a "fault" upon the flow and accumulation of underground water.

be put down through the original layer, A, to the top of C, the water which has percolated through the bed B down to this point will be forced upwards by the pressure of the water in the surrounding rock, and will therefore rise in the hole to nearly the level which it occupies in the bed B. Or, in the absence of a bore-hole, the water will escape from the saturated bed B, by oozing out at the surface, near the junction of the adjacent strata. It is obvious, from this illustration, that faults must be of great importance in determining the position of springs and wells.

Artesian wells.—It frequently happens that the beds of rock, instead of having a uniform dip, slope first downwards and then upwards, so as to assume a basin-like form, such as that shown in Fig. 24. Here it is seen that the

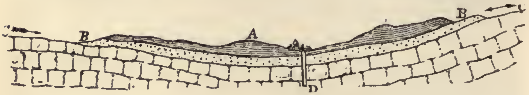

Fig. 24.—Diagrammatic section across the London basin.

strata on opposite sides slope in opposite directions, as indicated by the arrows. Rain falling upon the exposed edges of the porous rock B B, will be readily absorbed, and will percolate through the pervious material until it reaches the bottom of the trough, where it will accumulate, and of course be accessible to the boring-rod. If, therefore, a bore-hole be put down through the impervious bed A, it will tap this reservoir of water, and the liquid will then rise to a height dependent on the level of the water in the bed B B. The laws which regulate the flow of water underground are precisely the same as those which regulate its flow above ground. The water pent up in the bed B B will therefore rush up the tube, and tend to find its own level.

This arrangement of strata in Fig. 24 may be taken to represent, roughly, the disposition of the rocks beneath London. The beds in that area have been thrown into a trough-like form, and have thus produced what is commonly known as the *London basin*.[1] Yet it must not for a moment be supposed that they lie in a deep hollow anything like that of an ordinary domestic basin, or even like that represented by the curves in the figure. It is true the rocks to the north and south of London slope gently inwards, and thus produce a depression, but it is a depression of the very shallowest kind. The inclination is indeed so gentle that it can scarcely be shown in a diagram brought within the compass of a page of this book. Hence most diagrammatic sections, as already explained (p. 14), are necessarily exaggerated, and false notions have thus got abroad as to the nature of the London basin. It is only when true sections are drawn, having the vertical heights represented on the same scale as that of the horizontal distances, that its extremely gentle concavity becomes apparent.

With this caution, we may proceed to examine more closely the section in Fig. 24. This may be taken to represent an exaggerated section across London, from north to south; A representing the London clay, and B indicating the position of certain underlying rocks called by geologists the *Lower London Tertiaries* which in the neighbourhood of London are for the most part of a sandy or permeable nature.

When a deep boring is made through the London clay down to the Lower Tertiary sands, or still deeper, into the chalk, which underlies them in the position represented by C C, the water tends to rise in the tube, and may even reach the surface and overflow. If the point from which the water is tapped be in low ground, as would be the case with the boring D in the hollow of the London basin, it is necessarily at a much lower level than that of the outcrop of the beds along the margin of the trough, as at C C. The water is consequently forced up the tube by the pressure of the liquid with which the water-bearing bed is charged. When this pressure is sufficient to cause the water to flow over the surface of the bore-hole, it produces what is termed an **Artesian Well.** This name, however, is now commonly extended to other wells in which the water, without overflowing, yet rises to a sufficient height to be economically employed. Artesian wells are of great antiquity in the East; in North-Western Europe they were first constructed in the province of Artois, in France, whence the name *Artesian*.

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[1] The London basin, or area around the metropolis, forms only a small portion of the Thames basin. The two are to be kept carefully distinct.

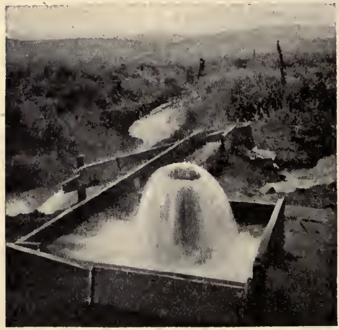

FIG. 25.—An artesian well. From *The Motion of Underground Waters*, by Mr. C. S. Slichter, U.S. Geological Survey.

Having explained the origin of ordinary springs and the nature of Artesian wells—which in truth are merely artificial springs—it is now time to show that springs are the immediate source of all the fresh water of rivers, except the small portion derived from the rain which falls directly into them.

London water supply.—The chalk formation is the most important source of water supply in the South of

England, but it is not an inexhaustible reservoir. A report prepared by Sir Maurice Fitzmaurice, Chief Engineer of the London County Council,[1] points to a steady and increasing shrinkage of the available sources of water in the valleys of the Thames and its tributary the Lea. There seems to be no doubt that the water level of the chalk below London is falling from 12 to 18 in. per annum, and that wells, springs, and streams in the catchment basin of the Thames are being depleted. The numerous deep wells in and around London are abstracting water faster than it can flow in from the outcrop, while pumping operations in chalk areas are causing neighbouring springs to dry up, and are diminishing the amount of water which reaches the Thames from tributaries. The large and increasing population of London has greatly increased the demand upon the water resources, so that in 1902 more than 200 million gallons were delivered by the water companies every day. About one-fifth of this supply was obtained from springs and wells, and the remaining four-fifths were taken directly out of the Thames and Lea.

Source of a river.—In seeking the origin of the water brought down by a river to the sea, it is necessary to trace the river to what is commonly called its "source" (Fig. 26). On ascending a navigable river from its mouth, it is observed that the size gets smaller, the volume of water becoming less and less. Following the many windings of the river we observe the stream growing more narrow and more shallow, until it ceases to be navigable. The main stream splits up into a number of smaller streams, forming the **head-waters** of the river, and it is often by no means easy to say which of these streams should be followed up in seeking the true source (Fig. 27). Nor does it much matter, for the origin of any one of them is much the same as the origin of any of the others.

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[1] "Shrinkage of the Thames and Lea." Report presented to the Water Committee of the London County Council, February, 1903.

Although a spring may be called the "source" of a river, it should be remembered that the quantity of water delivered by the spring is quite insignificant when compared with that derived from the numerous streams which flow into the river at various points along its course (Fig. 29). Every tributary helps to swell the bulk of the river by discharging its water into the main stream; yet it does not follow that the river is necessarily increased in width by the influx of this water for it often happens that the additional supply is carried off by increased rapidity of flow. As the river rolls along, it receives a number of these feeders, or **affluents**,[1] which

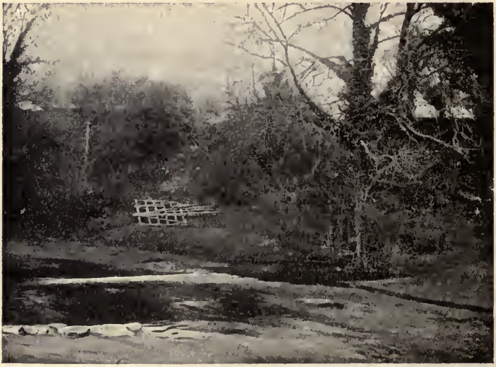

Photo. *H. W. Taunt.*

FIG. 26.—Thames Head. First Spring. Winter.

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[1] *Affluent*, from the Latin *ad* and *fluo*, "to flow." The junction of an affluent with the main stream is termed the *confluence*, or place where they "flow together." Thus, the town of Coblenz takes its name from the Latin form *Confluentia*, in allusion to its position at the junction of the Moselle and the Rhine.

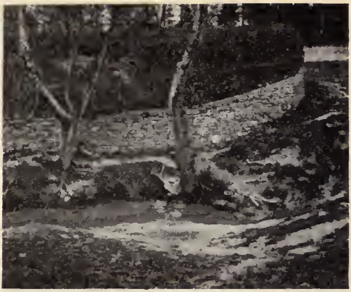

Photo. *H. W. Taunt.*

FIG. 27.—Seven Springs: source of the Churn. This is sometimes regarded as Thames Head, or the highest point from which the river rises.

empty themselves into the river, some on one side and some on the other.

Right and left banks of a river.—It is obviously convenient to have some ready means of distinguishing the two banks of a river. For this purpose, geographers have agreed to call that bank which lies upon your right side as you go down towards the sea the **right bank,** and to call the opposite side the **left bank.** All that you have to do then, in order to distinguish the two sides, is to stand so that your face is in the direction of the mouth of the river, and your back consequently towards its source, when the right bank will be upon your right hand and the left bank upon your left hand.

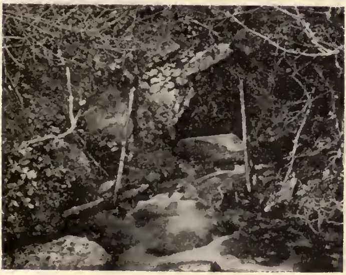

Photo. *H. W. Taunt.*

FIG. 28.—Head spring of the Coln, a tributary of the Thames, near Andoversford.

River basin.—Rivers flow from high to low ground; hence if the reader were to travel up a river by walking along its banks, he would find himself continually going uphill. The rapidity with which a river flows depends of course upon the amount of slope in its bed; where the fall is great the stream is rapid; where small the stream is slow. What is true of the main stream is equally true of any one of the tributaries; the source is always higher than the mouth. The tract of country drained by a river and its tributaries is called the **basin** of the river. Thus the shallow depression through which the Thames and its tributaries flow is consequently called the *Thames basin*; while the deepest part of the basin, that in which the main stream flows, is termed the *Thames Valley* (Fig. 30).

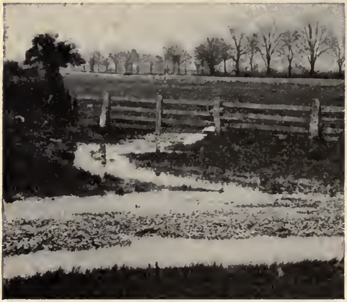

Photo. *H. W. Taunt.*

Fig. 29.—The first tributary of the Thames, about one mile below Thames Head.

Perhaps the term "basin," just used, is one which is likely to mislead unless properly qualified. It must be borne in mind that the hollow at the bottom of which a river runs is nothing like the deep hollow associated with our ordinary notion of a basin; it is, in fact, so slight a depression that it would perhaps be better to speak of the "dish" of a river rather than of its "basin."

Water-parting.—In ascending any hills surrounding a river basin many little streams would be met flowing down to feed the affluents of the river. But having reached the summit of the hill, and walked on in the same direction, you would soon begin to go down-hill, and then meet fresh streams running in an opposite direction to those you had left. These new streams cannot possibly flow into the same river, for to do that the water would have to run up-hill. By following these streams, however, you would find that they ultimately flow into a river entirely distinct from the first. The high land which forms the divisional line between two contiguous river-basins is called the **water-parting.**

Instead of "water-parting," some writers employ the term **watershed**; but although the two words originally meant precisely the same thing, the latter has become rather ambiguous. "Watershed" is a word which has been borrowed from German geographers. The term "water-parting" has been introduced as the English equivalent of the German *Wasserscheide*, or the boundary-line between two adjacent river-systems. Such a line has been called

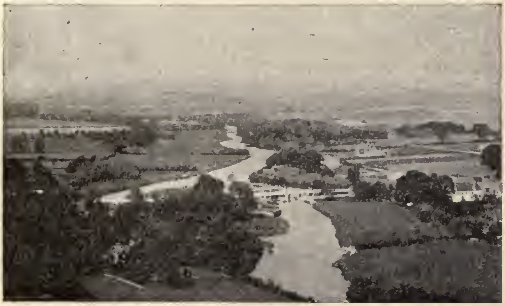

Photo. *H. W. Taunt.*

FIG. 30.—Valley of the Thames from Streatley Hill, Berkshire.

"the summit of drainage"; and in the north of England, where it often separates one estate from another, it is known as "the heaven-water boundary." It must be remembered, however, that the water-parting is not necessarily the summit of a range of hills, like the ridge of a roof. Frequently, indeed, the ground is only relatively high; but the water easily finds the slope, however small, and runs down it, thus showing at once the direction of the water-parting.

River basins and water-partings of England.—A little consideration will show that water-partings may be drawn on a map of any country, so as to divide the entire region into a series of river basins. Fig. 31 is a map of England and Wales thus completely divided into river basins, separated one from another by water-partings, which are indicated by dotted lines. All the rivers which empty themselves into the sea on the eastern side of England may, in this way, be separated from those which run into the western seas, and both systems may be separated from the southern rivers which open into the English Channel: the northern drainage is insignificant. We thus obtain the general water-parting of England and Wales, distinguished in the map by a thick line. This is a sinuous line running through Scotland and the north of England, down the Peak of Derbyshire and through the Midland counties, till it gets as far south as Salisbury Plain. Such a line divides the western drainage of the country from its eastern drainage. At Salisbury Plain the line splits into two branches, one stretching to the east coast and terminating somewhere about Dover, the other striking to the west coast and terminating at the Land's End. To the south of this great east-and-west line, all the rivers flow into the English Channel. This three-branched line consequently represents the main water-parting of the country; it is in fact the general high-level line of Britain, though it has no direct relation to the mountain systems of the country.

Enough has been said, in this chapter, respecting the nature and origin of springs, to show that all such sources

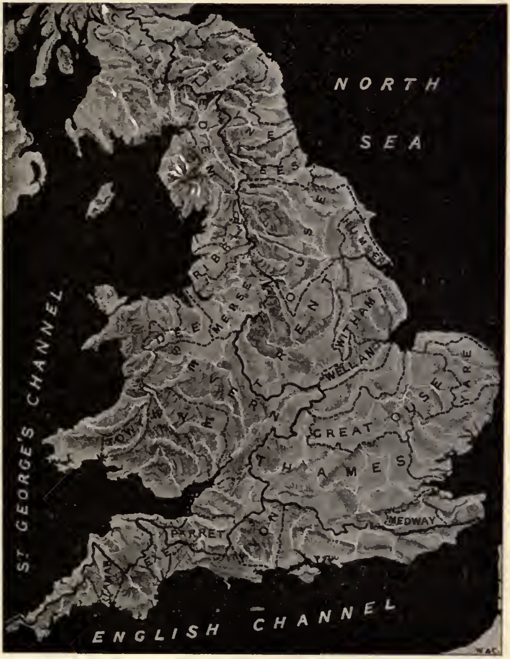

FIG. 31.—River basins and water-partings of England and Wales.

of water owe their origin, directly or indirectly, to the rain which falls upon the collecting ground, and finds its way through the pores and cracks of the rocks beneath. Proximately, the sources of rivers are to be found in springs; but, ultimately, it must be traced to rain. It is true the springs feed the river, but it is the rain that feeds the springs. It will therefore be necessary, in the next chapter, to study the formation of rain and kindred phenomena.

CHAPTER III

CLOUDS AND RAIN

Steam and water vapour.—In travelling by steamer, it often happens that on going to that side of the boat towards which the wind is blowing the passenger suddenly finds himself in a shower of fine rain. This artificial shower is produced by the steam which issues from the waste-pipe being cooled down by contact with the surrounding cold air until it is condensed in the shape of drops of liquid. Every natural shower of rain is produced by a process of condensation similar to this, but carried on in the higher regions of the atmosphere.

It is instructive to observe the dense clouds of steam which roll forth from the spout of a kettle of boiling water, or from the escape-pipe of a steam-engine. In most cases, nothing can be seen close to the point from which the vapour issues, and it is only at some distance from this point that the white clouds first make their appearance. But, since that intervening space lies directly in the path of the issuing vapour, it is clear that it must be traversed by steam, though the eye fails to detect it. In fact, the steam, or water vapour, when pure and uncondensed, is as transparent, as colourless, and as invisible as the air we breathe or the gas we burn. It is only when the vapour is partially

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condensed, and therefore ceases to be true vapour, that it appears in those cloudlike-forms which are popularly called "steam." Could you look into the interior of a kettle or of a boiler from which clouds of so-called steam are issuing, you would see absolutely nothing in the space above the boiling water. It is only necessary to boil water in a glass vessel, such as a Florence flask, in order to observe that the steam remains invisible until exposed to some chilling influence, such as that of a body of cold air (Fig. 32).

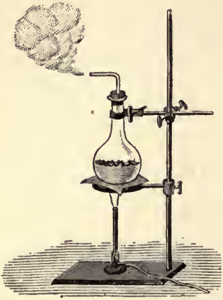

FIG. 32.—The water vapour inside the flask is invisible, but when it escapes from the tube and is cooled, it forms a cloud of steam.

Moisture in the atmosphere.—More or less of this water vapour or steam, in its invisible condition, is constantly present in the surrounding atmosphere. It rises into the air from every exposed piece of water which is warmed by the solar heat, just as steam is generated from water which is artificially heated. Whether it be evolved rapidly with formation of bubbles, as in the ordinary process of boiling, or slowly and quietly, as in the course of evaporation, the product is the same—namely, invisible water vapour. But let the air thus charged with moisture be sufficiently cooled, and its burden of vapour, previously unseen, makes its appearance as cloud, or mist, or fog. And under certain atmospheric conditions, the condensation proceeds further, until the moisture ultimately falls to the earth in the shape of rain. Every one knows that when a cold object, such as a steel knife, is held in a cloud of steam, the surface rapidly becomes covered with drops of condensed water; and the drops of water in a shower of rain have been generated by a similar process of condensation, carried on in nature.

In most cases, the atmospheric moisture passes through the condition of visible cloud, or mist, before finally condensing as rain. Yet it sometimes happens that rain falls from a clear and cloudless sky. By local refrigeration after sunset, the vapour invisibly diffused through the atmosphere is condensed at once into excessively fine drops of liquid water, forming the rain called *serein*. But such phenomena are rare; and, as a rule, we may fairly expect the formation of rain to be preceded by that of cloud.

Nature of a cloud.—Many opinions have been advanced to explain the precise condition in which water exists in a cloud. At one time it was commonly supposed that a cloud is made up of a vast number of minute vesicles, or little watery bladders, which remain suspended in the air by reason of their small size and hollow structure. It appears probable, however, that the water is merely condensed in a very finely-divided state, its extremely minute drops remaining suspended in the surrounding moist air, as fine dust does. Such droplets have, indeed, been expressively called "water-dust," and probably each tiny drop has formed round a minute speck of dust as a nucleus. It is supposed that, in the upper regions of the atmosphere, the watery cloud-drops are frequently frozen into ice—a supposition strongly supported by the optical characters of certain clouds, which appear to be explicable only by the presence of a crystalline structure.

Formation of cloud.—When a current of warm air, laden with moisture, rises from the surface of the earth, and reaches the higher and colder regions, the uppermost portion of the ascending current deposits its moisture in visible form, and thus produces a cloud, supported at the top of an invisible column. If the temperature fall, or the course of the current be arrested, the cloud descends, and, regaining the lower and warmer regions, returns to its original state of invisible vapour, and thus becomes dissipated. Observe the clouds of steam which issue from the chimney of a locomotive engine, and you will see that as they float away in the air they gradually disappear. The minute particles of water of which they are composed, in fact, are speedily converted into invisible vapour, and mingle with the atmosphere; and the drier and hotter the air happens to be, the more rapidly does this change take place.

Again, when a current of warm and moist air meets a colder current its temperature is reduced, and more or less of its moisture is deposited. In Great Britain the south-west winds, having swept over the waters of the Atlantic, are charged with moisture, and are ready to deposit a portion of their freight whenever they are sufficiently chilled, as they may be, for example, by meeting a cold east wind. Hence, south-west winds act as the chief rainbearers to the British islands.

Classification of clouds.—So fantastic and varied are the forms presented by clouds that they seem, at first sight, to defy scientific classification. In 1802, however, Mr. Luke Howard, an eminent meteorologist, proposed in an essay *On the Modification of Clouds*, a system of nomenclature and classification, which has since been so commonly adopted that his terms are frequently used, even in popular descriptions of scenery. The international system [1] of cloud classification now followed by meteorologists is based upon Howard's scheme of nomenclature; but ten classes of clouds are recognised, arranged according to the altitude at which they usually occur. Reference to Figs. 33–36 will convey a better idea of the typical forms of clouds than could be got from any long technical descriptions.

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[1] See *Hints to Meteorological Observers. Prepared for the Royal Meteorological Society.* By W. Marriott. (Stanford. 1*s.* 6*d.*)

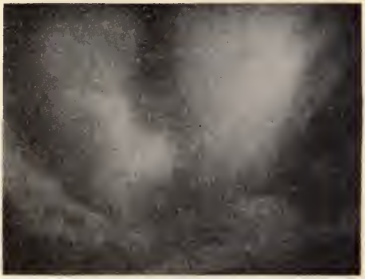

FIG. 33.—Cirrus cloud. Reproduced by kind permission from a photograph by Captain D. Wilson-Barker.

Delicate white fleecy clouds generally of a white colour may often be seen floating in the upper regions of the atmosphere, sometimes arranged in belts running in more or less parallel directions. Frequently a cloud of this class will present the appearance of hair, or feather, with its fibres curled, and hence it has received the name of **cirrus**[1] (Fig. 33). The cirrus clouds are always lofty, sometimes as much as ten miles above the surface of the earth; and, being wafted along by currents in the upper regions of the atmosphere, they may often be seen to move in a direction opposite to that of the wind which happens to be blowing over the surface.

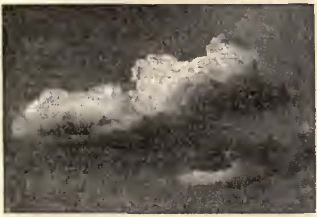

FIG. 34.—Cumulus cloud. Reproduced by kind permission from a photograph by Captain D. Wilson-Barker.

Very different from the cirrus are the well known **cumulus**[2] (Fig. 34), or wool-pack clouds, consisting of towering heaps of cloud having a dome-shaped upper surface and a nearly horizontal base. Different again are the sheets of lifted fog which are often to be seen extending widely in a horizontal direction, and are known consequently as the **stratus**[1] (Fig. 35). The fourth main group of cloud forms is the **nimbus**[2] or rain-cloud, defined as a thick layer of dark clouds, without shape and with ragged edge, from which rain or snow generally falls.

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[1] *Cirrus*, a curl.

[2] *Cumulus*, a heap.

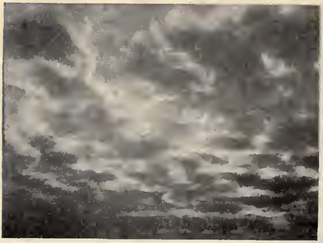

FIG. 35.—Stratus cloud. Reproduced by kind permission from a photograph by Captain D. Wilson-Barker.

Composite clouds.—It often happens that the clouds under observation do not fall into any place in the foregoing general classification. Instead of belonging definitely to any one class, they may combine the characters of two or more groups, and in such cases expressive designations are framed by combining the preceding elementary terms. Thus, following the international scheme of nomenclature from cirrus—the highest type—to stratus—the lowest, we have first the compound form **cirro-stratus**, consisting of a thin film of cloud sometimes completely covering the sky and at others presenting a formation like a tangled web. These clouds, like the cirrus, are made up of minute ice-particles (p. 39), since they often produce those coloured circles known as **halos** when they come between us and the sun or moon. The beautiful effect of what is known as the **mackerel sky** is due to numerous small globular masses or white flakes of the composite form termed **cirro-**

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[1] *Stratus*, or *stratum*, a bed.

[2] *Nimbus*, a rain-cloud.

cumulus (Fig. 36). In like manner, we may have **strato-cumulus,** consisting of globular masses, or rolls of dark cloud frequently covering the whole sky, especially in winter; and **cumulo-nimbus**—the thunder-cloud or shower-cloud, made up of heavy masses which rise in the form of mountains, turrets, or anvils, generally having a sheet or screen of filmy appearance above, and underneath a mass of cloud similar to nimbus. The two remaining forms of the international system are termed alto-cumulus and alto-stratus, and are placed between the cirro-cumulus and the strato-cumulus. Before leaving the nomenclature of clouds, it may be useful to remark that the term **scud** is applied by sailors to a layer of nimbus cloud which has separated into shreds, or to small loose clouds drifting rapidly underneath a large nimbus.

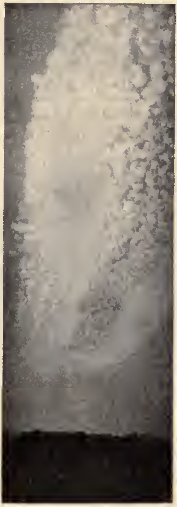

FIG. 36.—Cirro-cumulus cloud. Reproduced by kind permission from a photograph by Captain D. Wilson-Barker.

In meteorological reports, it is convenient to express approximately the proportion of sky which, at any given time, is covered by cloud. This is effected by using an arbitrary scale. Thus, a clear blue sky is represented by a cipher, while a sky completely covered or overcast is designated by 10; the intermediate numbers from 0 to 10 being used to express varying proportions of cloudiness.

Mist or fog.—It has been shown that, when water vapour condenses in the upper regions of the atmosphere, it gives rise to the formation of clouds. But, if the condensation occurs near to the surface of the earth, it produces those visible vapours which are known as *mist* or *fog*. Beyond the difference in the place of origin there is really little or no distinction to be drawn between a fog and a cloud. A fog is a cloud resting on the earth; a cloud is a fog floating high in the air. When in ascending a 'cloud-capped' mountain, we enter the region on which the clouds rest, we find ourselves in a dense white fog. But after traversing this and reaching the clear summit, perhaps a thousand feet higher, the fog which we have left below once more appears under the guise of a mass of clouds.

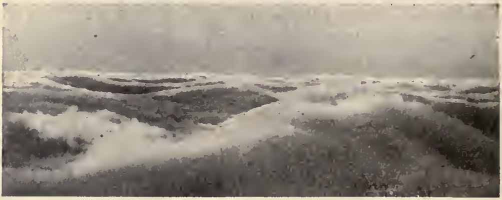

FIG. 37.—Above the rolling mist. From a photograph of fog taken by Mr. A. McAdie on Mount Tamalpais, San Francisco.

Whenever moist air near the surface of the earth has its temperature sufficiently reduced, the moisture is condensed as mist or fog. Thus fogs almost constantly hang over the banks off the coast of Newfoundland, where they are produced by the warm moist air which blows over the Gulf Stream [1] coming in contact with the cold air of the Labrador current. In like manner, icebergs are often attended by fogs, simply because the mass of ice cools the surrounding air, and thus precipitates its moisture. Mountains, again, are frequently enveloped in mist, since the warm air, on being driven up the slope of the hill, becomes chilled to the point at which its moisture is partially condensed (Fig. 38). So too the position of a river is often marked by mist; and this whether the water be colder or warmer than the overlying air: in the former case, the air is cooled down by contact with the water, and its moisture discharged; in the latter case, the warm water yields more vapour than the air can retain at the given temperature. The British Isles, washed by warm water on their western shores, are peculiarly subject to fogs; and, of all places, large towns seated on rivers are the most affected, since the artificial heat, coupled with the moisture of the air over the river, produces conditions favourable to the formation of fogs whenever the air becomes sufficiently cooled. The proverbial London fog owes its density and darkness to the smoke, or particles of carbonaceous matter, disseminated through the atmosphere and mingled with the partially condensed water.

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[1] It will be explained in Chapter XI. that the Gulf Stream is a body of warm water which flows from the Gulf of Mexico in a north-easterly direction; the Labrador current is a body of cold water coming down from the north along the coast of Labrador.

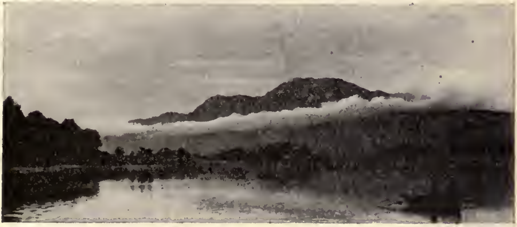


Photo. *W. M. Spooner and Co.*

FIG. 38.—Mist forming against Ben Lomond.

Rainfall.—So long as water remains in the state of cloud, or fog, its particles are so minute that they hang suspended in the air, or mount upwards on the slightest current. But, when these droplets run together, they produce drops too heavy for suspension in the atmosphere, and are then precipitated to the earth as rain. The **rainfall**, or amount of rain which falls in any given locality, is a most important element in determining its climate.

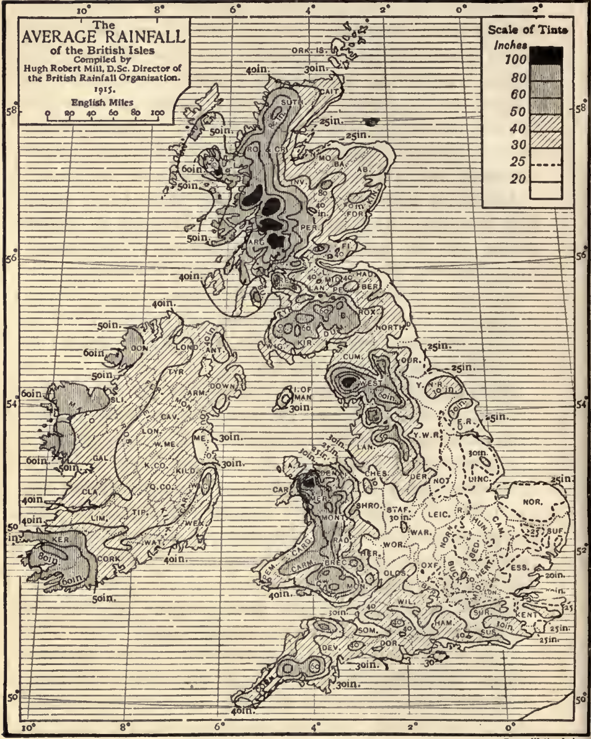
What does a meteorologist mean when he says, in his technical language, that the mean annual rainfall of a place, London, for example, is about 24 inches? By such a statement he means, simply, that if all the rain which falls on any level piece of ground at the place during an average year could be collected—none being lost by drying up, none running off the soil, and none soaking into it—then, at the end of the year, it would form a layer covering that piece of ground to the uniform depth of two feet. The year's accumulation of rain would thus form a vast mass of water. Remembering that an inch of rain represents about 100 tons of water to the acre, it will be found that every acre of land in a place having an average annual rainfall of 24 inches receives during the year, when the year is neither very wet nor very dry, not less than 2,400 tons of water in the form of rain.

Looking at the entire basin of the Thames, it may be said that the average rainfall is about 26 inches. Now the area of the basin comprises upwards of 6,000 square miles. Suppose then that we measured out a square space a mile in length on each side, and built upon this base a four-sided tower two and a half miles in height, which we completely filled with fresh-water; this enormous column would represent the quantity of water which falls upon the surface of the Thames basin in the course of twelve months. And it should be borne in mind that every drop of this water has at some time existed in the atmosphere as invisible vapour. In one sense, therefore, it may be truly said that a river has its source in the air.

British rainfall.—Observations extending over many years have shown that the mean annual rainfall is by no means the same throughout the British Isles. The wettest place is Seathwaite, in Cumberland, where the average rainfall is 131 inches, and then, in order, come Killarney, 57 inches; Ashburton, Devonshire, 51 inches; Falmouth, 42 inches; and Londonderry, 40 inches. The lowest average rainfall is about 23 inches, and among the places which receive this amount are Margate and Lowestoft on the East coast of England, and Apsley Guise and Hodsock in the Midlands.

In passing across England from east to west it is found that, as a rule, the rainfall increases. The average rainfall on the east side is about 25 inches, but among the western hills where the Thames takes its rise the fall is as much as 40 inches. A map upon which the mean annual rainfall throughout the British Isles is represented is reproduced in Fig. 39 from one prepared by Dr. H. R. Mill, director of the British Rainfall Organisation.

Distribution of rain.—In examining the distribution of rain, it will be found to be regulated partly by the physical features of the country, and partly by the character of the prevailing winds. In the neighbourhood of mountains, the rainfall is increased, since a mass of moist air, when forced up the side of a mountain is chilled, not only by the ascent into colder altitudes, but also by the expansion which it undergoes; and its moisture is consequently discharged. Among our western counties, in the neighbourhood of hills, the rainfall rises to eighty, or even to a hundred, inches, and upwards; while away from hills, though still in the west, it is only from thirty to forty-five inches. A table-land, or high plain surrounded by mountains, will generally receive but little rain, since the winds which reach it have been more or less drained of moisture in sweeping over the surrounding hills. For a like reason, but little rain is likely to fall on the lee side of a high hill, and many mountains, consequently, have a wet and a dry



Emery Walker Ltd. sc.

Fig. 39. Rainfall Map of the British Isles.

side; the wet side being, of course, that towards which the predominant winds blow. As regards the influence of winds on rain, it is evident that, when air has blown over a large expanse of warm water, it must have become laden with moisture, which will be readily precipitated on exposure to refrigerating influences. Hence, as in Britain, so in the greater part of Europe, the southerly and westerly winds bring rain; and most rain falls in the exposed westerly parts, such as the coasts of Portugal, Spain, France, Britain, and Norway. There are certain conditions, however, under which rain is brought to our islands by easterly rather than by westerly winds.

Abundant rainfall.—It is in those regions in which the sun's heat is intense, and powerful currents of highly-heated air, saturated with water vapour, are raised into the atmosphere, that the heaviest rains occur. But the heavy tropical rains are usually confined to definite periods—the **rainy season**—and little or no rain falls at other times of the year. Thus at the wettest place in the world, Cherrapunji, situated on the Khasi Hills, 200 miles north of the Bay of Bengal, the average rainfall is nearly five hundred inches, half of which is received in the months of June and July, and ninety-four per cent. during the six months from April to September inclusive.[1] During these months the prevalent winds are from the Bay of Bengal in the south, while during most of the other six months, the winds blow mostly from the south-west. This accounts for the difference between the monthly precipitation at Cherrapunji and neighbouring places, and also provides an instructive illustration of conditions favourable to an abundant rainfall.

Dry regions.—The principle that the side of a mountain facing a prevalent wind blowing from the sea receives a good supply of rain is exemplified in all parts of the world, and there are many cases in which regions, where little or no rain falls, owe their aridity to position on the leeward side of mountain ranges. Thus, in South America the south-east winds, after passing across the continent, encounter the Andes and lose nearly all their moisture, so that the air which descends on the western side is extremely dry, with the result that along the Pacific coast there is a narrow belt which is almost rainless. Leh, on the leeward side of the Himálaya Mountains, has an annual rainfall of less than three inches, and the annual precipitation over the entire extent of Tibet is very small. The effect of the Himálayas is intensified, however, by the extreme elevation of the Tibetan plateau. The desert of Gobi owes its dryness partly to elevation, partly to the fact that the prevalent winds come from a desert region, and partly to the extensive range of mountains on its south-east side. The fact that the average elevation of the Sahara is more than 1,500 feet no doubt contributes to the smallness of the rainfall over the desert. Other conditions which tend to make rainless regions are absence of winds and position in the interior of a large continent.

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[1] *Contributions to Meteorology.* By Prof. E. Loomis. Chap. III. 1889. (New Haven, Connecticut, U.S.A.)

Forests and rain.—It is persistently stated that where forests have been destroyed the amount of rainfall has been diminished; in other words, that a wet climate may be changed into a dry one by cutting down the forest trees, or a dry region be made a moist one by afforestation. There is, however, little ground for this belief. Taking an extensive area into consideration, it appears to be conclusively proved that forests do not increase rainfall, but they do prevent the rain that falls in their neighbourhood from being wasted by evaporation. Forest soils absorb more moisture and evaporate it less quickly than soils not covered with vegetation. When forests are destroyed, the fertile, moisture-holding soil which the trees protected often becomes too dry to be of any service and is blown away by the wind, leaving bare rock behind. Hence, though forests do not appreciably affect the rainfall, they are of decided value in preserving the moisture in the ground.

Red rain.—A large amount of reddish or yellowish dust is occasionally brought down during rainstorms in the early months of a year in our islands and other parts of Europe. The dust sometimes falls in such large quantities that the streets are stained red with it, much to the alarm of people who do not understand the cause of the phenomenon. Microscopical examination has shown that this red rain or blood-rain invariably owes its tint to the presence of coloured dust, which in most cases has been brought from the Sahara. Fine sand is raised to a great height by one of the "dust devils" or whirlwinds of the desert and carried to a considerable distance before the particles reach the ground. If rain happens to fall through such a cloud of suspended dust, much of the material is naturally carried down with it, and this produces coloured stains when the rain has dried up.

Rainy days.—As we recede from the hotter regions of the earth either to the north or south, the rainfall, as a rule, diminishes, but the number of rainy days in the year increases; so that, speaking roughly, it may be said that, where the rainy days are fewest, the amount of rain is greatest. In temperate regions, the number of rainy days varies greatly in different localities, and in different seasons. But it is difficult to know exactly what is meant by so vague a phrase as a "rainy day." To secure uniformity among observers, meteorologists regard as a "rainy day," every day on which the rainfall is not less than one-hundredth of an inch.

From an examination of the records obtained in England and Ireland during the last twenty years of the nineteenth century, Mr. F. C. Bayard has found[1] that Londonderry has the greatest number of rainy days—rain falling on the average 243 days in a year—and Weymouth the smallest number, 153 days. With the solitary exception of Weston-super-Mare, the western stations at which the records are kept have more rainy days than the eastern stations.

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[1] "English Climatology, 1881–1900." *Quarterly Journal of the Royal Meteorological Society*, January, 1903.

Wet and dry months.—Rain may fall in the British Isles at any time of the year, but some months are notoriously wetter than others. The wettest months, however, are not the same at all places. Mr. F. C. Bayard's examination of rainfall records obtained in various parts of England and Ireland has shown that October is the wettest month at most places, and April appears to be the month in which the rainfall is generally the lowest of the year. No districts have their maximum rainfalls in July or September, so that these may be considered as fairly dry months. Our

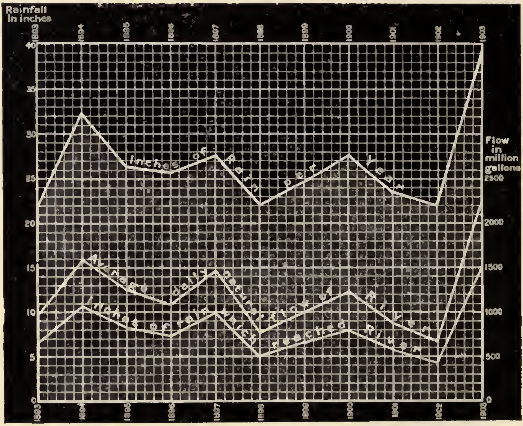

FIG. 40.—Rainfall in Thames basin, and average daily natural flow of the river for the years 1893–1903. From a report by Sir Maurice Fitzmaurice.

rainy season may roughly be said to extend over four months in the latter half of the year and our dry season to be spread over five months in the first half.

Wet and dry years.—It is matter of common observation that the rainfall varies not only in different localities, but in the same locality at different times. One year may be much wetter than another. Thus, taking the whole of the British Isles, the driest year in the period from 1866 to 1902 was 1887, when the average of all the rainfall records of the year was about 26 inches. The wettest year was 1872, with a rainfall of 49 inches, or nearly twice as much as in 1887. The average rainfall over the principal wheat-producing districts of our islands for this period of thirty-seven years was 27·5 inches, and the average over the principal grazing districts was 41·1 inches. A decided difference is thus shown in the amount of rainfall over these two areas. The average rainfall of the whole country is 34·3 inches.

Measurement of rainfall.—It may be useful before quitting the subject of rain, to explain how the rainfall at any given station may be determined. Although the operation is extremely simple, numerous kinds of rain-gauge have been devised. The accompanying figure (Fig. 41) represents a simple form generally used by meteorologists. The instrument consists of little more than a circular metallic funnel for catching the rain, and a vessel for storing it. All the rain which falls upon the open mouth is collected,

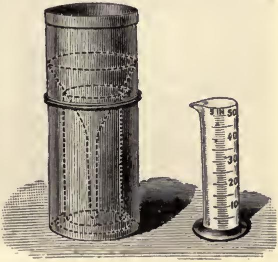

FIG. 41.—A rain-gauge and measuring jar.

and, when collected, is exposed to very little loss by evaporation. The area of the collecting vessel varies in different forms of apparatus, the Meteorological Office employing a funnel eight inches in diameter. By placing a deeper cylinder around the top of the funnel, snow may be collected ; but there are great difficulties in making accurate observations on a fall of snow. It is notable that different amounts of rain will be collected by gauges placed at different heights in the same locality; a gauge at a low level always reading higher than one above. In all cases the instrument must be placed in a freely-exposed situation with the top of the rim one foot above the ground and quite level. Every morning at nine o'clock, the rain collected during the preceding twenty-four hours is transferred from the collecting can to the graduated measure-glass, and its amount accurately recorded.

Self-recording rain-gauge.—It is often of interest to know the amount of rain which falls in a period of less than twenty-four hours; and though this can of course be determined by measuring the rain collected by a gauge during a storm or any short period, a more convenient means of finding the rate of fall is provided by a self-recording rain-gauge. There are several instruments of this kind available, but it will be sufficient to refer to the one of which the parts are shown in Fig. 42. In this instrument

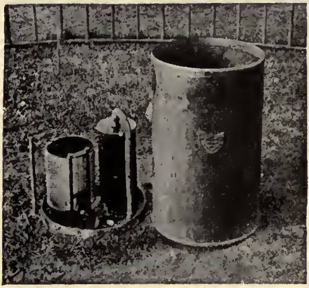

FIG. 42.—Standard self-registering rain-gauge, made by Mr. F. L. Halliwell, Southport.

the rain from a standard deep-rimmed copper receiver passes through a wide pipe to a cylinder in which there is a float bearing a vertical rod that raises or lowers a sliding pen. As the water accumulates in the cylinder, the float and pen rise, the latter recording the rainfall upon a waterproof paper chart fixed upon a drum which is kept slowly turning by means of clockwork. When the cylinder has collected one inch of rain, the cylinder is automatically emptied and the recording pen falls down to the zero position. Part of a record obtained with one of these raingauges at Camden Square, London, in 1903, is reproduced in Fig. 43.

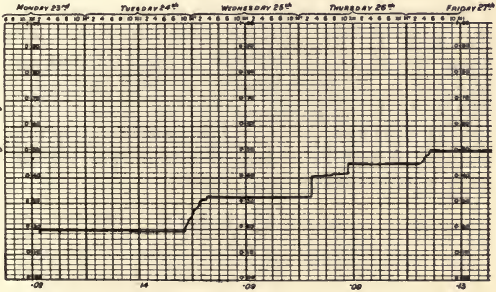

FIG. 43.—Part of a rainfall register, made at the "British Rainfall" Observatory, London, on Feb. 23–27, 1903, by Halliwell's self-recording rain-gauge.

Disposal of rainfall.—Of the rain which falls in any given district, part is lost by evaporation and passes invisibly into the air; at the same time another part soaks into the soil, and this also appears to be lost; whilst part again flows off the surface of the ground to lower levels. Rain is thus disposed of in a threefold way, but the relative proportion between the three parts will vary considerably in different localities, and at different times in the same locality. It is dependent on climate and season, on the character of the soil, and on the physical features of the district. But, whatever the proportion may be, the rain which is absorbed by the ground and that which flows off the surface will contribute sooner or later to the formation of springs and streams. And in this way the rains indirectly nourish the rivers, since we have already seen that rivers are mainly fed by springs and streams. It must, however, be remembered that, independently of the effects of evaporation, the quantity of water which reaches a river may be less than that which falls in the shape of rain upon its catchment basin; inasmuch as some may go to feed the springs of other catchment basins. And, on the other hand, the quantity of water conveyed by a river may be indefinitely greater than that which falls upon its catchment basin, if the geological structure of the basin is such as to lead the rain from beyond its limits into the springs of the river.

CHAPTER IV

NATURE AND ORIGIN OF DEW, SNOW, AND ICE

Moisture in air.—Atmospheric moisture is frequently condensed in other forms than that of rain. If a glass of water recently drawn from a cold spring be brought into a warm room, it will be found that the outer surface of the glass gradually loses its brightness; a dimness soon creeps over the surface that was previously clean and bright, and, before long, drops of water may be seen trickling down the sides of the vessel. It is true that certain kinds of glass, such as some of the old Venetian, constantly exude moisture, or "sweat," so that after the surface has been dried it soon becomes moist again—an effect probably due to an excess of soda in the glass. But the moisture which appears on ordinary glass, under the conditions indicated above, is clearly due to an entirely different cause, since it is produced with equal readiness on glass of any chemical constitution, or indeed upon a vessel of polished metal. It is evident then that the moisture is not derived from the substance of the vessel itself; neither is it obtained by percolation through the walls of the vessel, for the metal has no sensible pores. The only remaining source of moisture is the surrounding medium, or the atmosphere. That medium always contains more or less water vapour ready to be deposited upon any object when sufficiently chilled, and the necessary refrigeration is brought about by the cold water in the glass or the metal vessel. Moisture which is thus deposited upon any cold surface, without production of mist, is termed **dew.**

Dew-point.—The proportion of water vapour that can be held in the atmosphere depends principally on the temperature of the air; the lower the temperature the less it retains. If charged so highly with moisture that it can take up no more, the air is then said to be **saturated.** When a body of moist air is cooled, the point of saturation is gradually reached; and, when saturated, any further cooling causes a deposition of dew: hence the highest temperature at which dew forms is called the **dew-point.** This temperature may be determined in a variety of ways, but most of the instruments used for this determination are based on the principle to which reference has just been made.

Formation of dew.—After sunset, on a clear night, the grass and other objects on the surface of the earth give off the heat which they have absorbed during the day, while the sun has been shining upon them, and their temperature is thus gradually lowered. The air in contact with these objects is also cooled; and, as it gets cool, it grows less able to retain its moisture, until at length the dew-point is reached, when drops of liquid are deposited on the blades of grass. Some bodies throw out, or radiate, their heat much more freely than others, and dew is therefore precipitated copiously upon such good radiators. Thus it may sometimes be seen in a garden that every blade of grass is bedecked with sparkling dew-drops, while the neighbouring gravel path remains almost dry. The grass has parted with its heat, and consequently become chilled, more readily than the gravel has cooled; and the dew is therefore distilled more abundantly upon the grass than upon the gravel.

Whatever prevents the radiation or giving-off of heat from terrestrial bodies tends to hinder the formation of dew. A cloud, for example, acts in this way, since it reflects, or throws back upon the earth, the heat which would otherwise be projected into space. Dew is therefore most copious on a cloudless night. A calm atmosphere also promotes the formation of dew, for it is obvious that agitation by currents of air must be unfavourable to local refrigeration; while it promotes the evaporation of any dew that may have been deposited.

Source of dew.—It was not until the beginning of the nineteenth century that so common a phenomenon as the formation of dew was thoroughly understood. Observations on the subject had indeed been made at a much earlier date, but it remained for Dr. W. C. Wells to undertake a systematic inquiry into the conditions under which dew is deposited. After much patient investigation he published, in 1814, his famous essay entitled *The Theory of Dew*, in which he put forward the simple explanation just described. The conclusions at which Wells arrived as to the conditions favourable and unfavourable to the deposit of dew have been substantiated by subsequent investigators, but experiments by the Hon. Rollo Russell, Mr. John Aitken, and others have shown that dew is only partly derived from the moisture in the air, much of it having its origin in vapour exhaled from the earth, or from the grass or other plants on which the dew appears. Moisture is continually being exuded by the leaves of plants; and in the absence of sunshine or wind it accumulates on the surface as drops of water or dew instead of being dried up as it is during the daytime. Vapour is also constantly arising from the earth, and this contributes to the formation of dew, so that though the upper surfaces of stones are not visibly bedewed on a clear night, the lower surfaces have often a heavy deposit. Ground covered with turf is kept moist even in dry weather, and as at night the blades of grass become cooler than the earth from which moisture is being exhaled, the vapour is condensed as dew upon them. Dew is thus derived not only from the general moisture of the air, but from water exuded by plants upon which the drops appear, and from water vapour exhaled from the ground.

In tropical climates, the amount of vapour which thus arises from vegetation and the ground at night and is condensed into water is very great, so that the writer of old time had some justification for his reference to "the mist that went up from the ground and watered the whole face of the earth."

Contraction caused by cooling.—Daily observation shows that almost everything gets smaller as it is cooled. Reduction of temperature, as a rule, causes the particles of which a given body is composed to be brought more closely together, and the substance consequently shrinks in bulk. Suppose a quantity of air is confined in a flask standing over water or quicksilver, as in Fig. 44, and that it is found at a given temperature to occupy a certain bulk; then, on lowering its temperature, the air will shrink in volume, or occupy less space, so that the water or quicksilver will tend to rise in the tube connected with the neck of the flask, and thus fill the space which would otherwise be left by contraction of the air. By careful observation it has been found that the shrinkage proceeds with great regularity as the air gets cooler, but

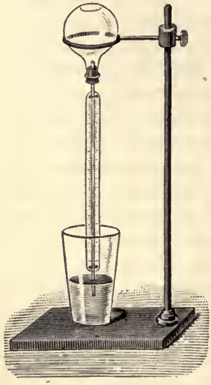

FIG. 44.—Experiment to show that air contracts when cooled and expands when warmed.

there is no need to trouble ourselves at present with the law of contraction.

Now water vapour, such as that present in the atmosphere, is a body which may be said roughly to have a constitution similar to that of the air with which it is associated. But when this vapour is cooled, a limit is soon reached, beyond which any further cooling brings about the condensation of the vapour as liquid water. In fact, water vapour, or steam, differs from fluids like air chiefly in the readiness with which it can thus be condensed or liquefied.

Expansion of water when freezing into ice.—Having in this way reduced the vapour to the condition of a liquid, it is important to observe the effect of still further lowering its temperature. As the water becomes cooled the bulk of the liquid is diminished. With most liquids, this reduction of bulk continues until their parts lose that freedom of motion upon one another which is characteristic of a liquid, and the mobile liquid passes into a compact rigid solid—**ice.** It is important however to note that water and a few other liquids, instead of continuing steadily to contract when cooled, reach a limit at which contraction stops and is succeeded by expansion, so that the solid water actually occupies a good deal more space than did the liquid from which it was derived (Fig. 45). When a waterpipe bursts during a frost, or a jug of water cracks as the liquid freezes, we are practically taught that water, during the process of solidification, undergoes a large increase of bulk.

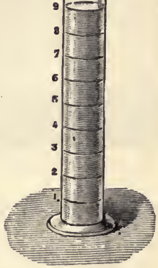

FIG. 45.—The ice-cold water represented in the jar would fill the jar if frozen into ice.

Relative weight of ice and water.—By reason of this expansion, a piece of ice necessarily weighs less than an equal bulk of water. If, for instance, a given bulk of water, measured at that temperature at which its relative weight is greatest, be found to weigh 1,000 pounds, an equal bulk of ice will weigh only 916 pounds. Hence ice floats readily in water, and floats with about one-tenth of its volume above the surface. This may be seen by dropping a lump of ice into a tumbler of water, and observing how much is exposed, and how much buried in the water (Fig. 46). Sea-water is denser, or heavier bulk for bulk, than fresh water; and therefore a mass of ice floats higher in the ocean, about one-ninth of its volume being then exposed. Hence, in those huge masses of ice which are frequently seen floating in the sea and are known as **icebergs**, the bulk of ice which is submerged is about eight times as great as that above water. But it must be remembered that the proportion of the submerged to the exposed part of the total height of the berg will be affected by the shape of the mass: and probably, in many cases, the shape of the berg is such as to cause it to sink to a very much smaller proportion of its total height beneath the surface than that represented in Fig. 46.

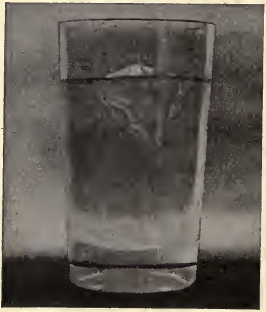
FIG. 46.—Ice floating in water.

Frost flowers.—It must not be supposed that the compact hard substance which is produced by the freezing or consolidation of water is a solid body without structure, like a piece of glass. Look at a bedroom window on a frosty morning, and you will probably find that some of the moisture present in the room has condensed upon the glass and frozen into solid ice; but you will see at once that this ice, instead of spreading itself uniformly over the surface, has shot out in definite directions, producing beautiful branching forms, not unlike the graceful fronds of a fern. The ice has, in fact, assumed forms which are extremely definite in themselves, and are known as **crystals.**

Crystallisation.—In the cavities of rocks which occur in many parts of Britain, there may be found a beautifully transparent substance, of great hardness, which puts on very definite shapes. These shapes, as represented in Fig. 47, usually look like little six-sided towers, shooting in all directions from the rock, and terminated at one end, or sometimes at each end, by a short six-sided spire. The faces are as smooth and bright as though they had been just polished on the lapidary's wheel; while the edges are as sharp and straight as though cut by a skilful workman. The ancients, who were familiar with these clear and colourless solid bodies as they occur in the granitic rocks of the Alps, supposed that they were composed of ice; that

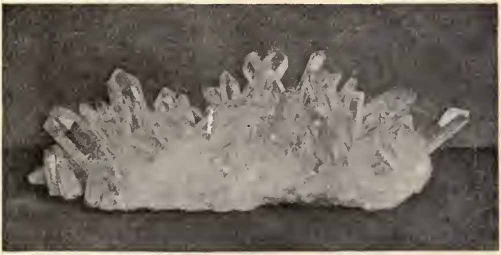

FIG. 47.—Group of rock-crystals. From a Report of the U.S. National Museum.

they were, in fact, nothing but water which had been congealed by so intense a cold that it was impossible to thaw it. And the Greek word for **ice** (*κρύσταλλος*, *krustallos*), thus suggested our term **crystal.** Even at the present day many crystallised minerals are vulgarly called "congealed water." The substance which has just been noted as having given rise to the word "crystal" is known as **rock-crystal,** and must be familiar to most readers, since it is used by the jeweller for working into ornamental objects, and by the optician for the manufacture of those spectacle lenses which are said to be made of "pebbles." The term "crystal" is now applied to all symmetrical solid shapes assumed spontaneously by lifeless matter.

Sizes of crystals.—Rock-crystal is sometimes found in crystals of gigantic size; at other times in excessively small specimens. This seems to show that the same species or kind of matter may assume forms unlimited in size. Specimens of rock-crystal have been found weighing more than 1 cwt.; and enormous crystals of this kind occur in Brazil, Madagascar, and Japan. Yet this same substance may be obtained in crystals so minute as to be seen only with the aid of a microscope. Such great variation of size in the same kind of crystalline matter has no parallel among living bodies. It is true that certain animals and plants, placed under very favourable conditions, may increase beyond their average size, but this increase is confined within comparatively narrow limits. A crystal, however, has absolutely no limit to its growth; it increases in size by addition of matter from the outside, and as long as new matter is thus presented to it, so long will it continue to enlarge. A small crystal of alum, for example, suspended in a saturated solution of the same salt, gradually grows larger by deposition of new alum in a solid form from the surrounding medium. This method of growth is therefore entirely different from that by which the growth of a living body is effected. It is as though a man could actually grow bigger by putting on coat after coat, instead of growing by the ordinary process of nutrition from within.

Crystalline form.—Just as there is nothing distinctive about the size of an individual crystal, so there is nothing distinctive about the size of the several faces of the crystal. A six-sided spire or pyramid of rock-crystal may have one face very large, and the next face so small as to be little more than a mere line. Size of crystal and size of face thus count for nothing, but what does tell for something in studying crystals is the slope or inclination which one face has to another; in other words, the angle made by two neighbouring faces. A set of faces symmetrically related, such as the six faces of the prism of rock-crystal, is called technically, a *crystalline form;* and the faces of any given form, however irregular in size and shape, are always inclined to one another at the same angle.

Snow crystals.—Although it is not every substance that can assume these regular forms, yet by far the larger number of bodies, including water, are capable of crystallisation. When water solidifies by reduction of temperature, the particles group themselves in definite directions, and thus produce regularly shaped solids, closely related to those of the rock-crystal. In fact the forms of ice and the forms of rock-crystal are characterised by the same kind of symmetry; a symmetry which is such that each crystal may be divided into six similar parts. The best examples of this hexagonal symmetry in solid water is furnished by crystals of **snow.**

If the air during a snow-storm be still, each flake that falls will be found to exhibit a regular shape. A perfectly-formed snow-flake is, in fact, an exquisite little crystal; but it commonly happens that a flake is made up of several of these crystals grouped together. Some idea of the beauty and variety of snow-crystals may be formed by reference to

Fig 48, which represents a few of the shapes photographed by Mr. W. A. Bentley, of Jericho, Vermont, U.S.A. More than a thousand different shapes have been photographed by Mr. Bentley, and no two of them are alike; but various as these are, they are all characterised by the same kind of symmetry. Some of these snow-crystals are simply solid rods or flat scales, each with six sides; others are six-sided pyramids, but the most common form is that of little six-pointed stars variously modified. Each star has an icy centre as a nucleus, from which six little spicules or rods of ice are shot forth at regular angles; and from the sides of these rays, secondary rays, or raylets, may be given off at the same angle, thus producing complex stars of great beauty, but, in spite of their complexity, always true to the hexagonal symmetry of the system to which ice belongs. Each part of the pattern is repeated round the centre six times, as is generally the case with the beautifully symmetrical shapes seen in a common kaleidoscope.

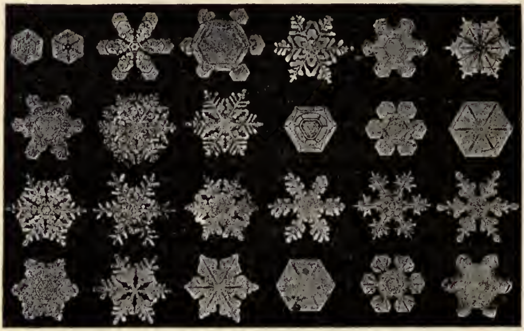

FIG. 48.—Snow crystals. From photographs by Mr. W. A. Bentley.

Ice flowers.—Although ice does not ordinarily exhibit well-defined crystals, it is nevertheless built up of crystalline particles interlaced together. This beautiful architecture can be revealed by submitting a block of ice to the action of a sunbeam, or even to a beam of electric light. Part of the heat enters the solid, and produces internal liquefaction, which proceeds with great regularity. Small shining points first appear in the ice, and around each of these points, as a centre, six rays shoot forth, producing figures such as those represented in Fig. 49. These beautiful forms, which commonly resemble blossoms with six petals or floral leaves, are not solid crystals, like our crystals of snow, but are simply hollow spaces of regular shape filled with water; they may indeed be called "negative" or "inverse" crystals, developed by the breaking down or "decrystallisation" of the ice.

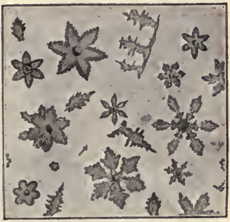

FIG. 49.—Ice flowers formed in a slab of melting ice.

Snow and sleet.—When there is much wind astir, the snow falls in shapeless masses, or even in small hardened pellets. If the snow-flakes become partially melted in their descent by falling through a layer of warm moist air, they produce what is called **sleet.** The largest snow-flakes fall when the temperature is near the freezing-point, and the smallest when the temperature is very low. It need hardly be said that snow is much lighter than rain; it is usually estimated at about one-tenth the weight of an equal bulk of water, but this proportion varies, of course, with the degree of compactness of the snow. In meteorological measurements, one foot of snow is taken as equivalent to one inch of rain. The loose texture of snow renders it an extremely bad conductor of heat, and a fall of snow thus acts like a mantle of fur thrown over the earth. The air entangled in the snow not only confers upon it this valuable property, but it also gives the snow its opaque white appearance, so different from the transparency of common ice. The light, instead of penetrating the snow, is thrown back from the ice-walls of each little air-cell or cavity, and thus becomes scattered, the snow losing its transparency; just as the foam of the sea becomes opaque white, by the light being scattered from the particles of water separated by air-spaces.

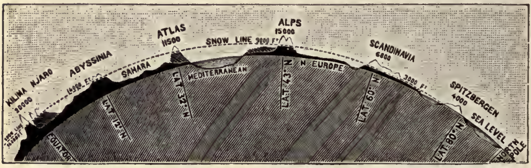

Fig. 50.—Height of the snow-line in various latitudes.

Perpetual snow.—When snow falls upon a mountain in winter, it may lie there unmelted until the warmth of summer returns to thaw it. But, if the mountain be very high, the summer-heat may never be strong enough to melt all the ice on its top, and the top will therefore be enveloped in perpetual snow. A line drawn at the level above which the snow never melts is called the **snow-line** (Fig. 50). On the north side of the Himálaya Mountains this line is 16,600 feet high; that is to say, all the snow which falls below this height is melted in summer, but all above remains unmelted. In the Andes of Peru the limit of perpetual snow is about 15,500 feet; but in passing northwards or southwards from these hot regions, we expect to find the snow-line descending; in the Swiss Alps, for example, it comes down to about

8,500 feet above the sea. Still farther north it reaches yet lower, and in the Arctic regions descends to the very sea-level; the winter's accumulation of snow is never completely melted by the summer sun, and the snow consequently lies on the ground all the year round.

Structure and formation of hail.—Snow is not the only solid form in which atmospheric moisture is precipitated. Occasionally, during a thunderstorm, it takes the shape of **hail,** which consists of hard masses of ice varying in size from the smallest shot to pieces several inches in diameter. These hailstones are in some cases perfect spheres, as though the drops of rain had rapidly congealed while falling. When broken open, a hailstone occasionally exhibits crystals shooting out from the centre in all directions towards the surface; but it is more usual to find a number of layers of ice, some clear and some opaque, coating a nucleus around which they appear to have been frozen in definite succession (Fig. 51). As a rule, hail falls in summer rather than in winter, and in the day rather than in the night. The origin of hail is still obscure, but it is probably formed

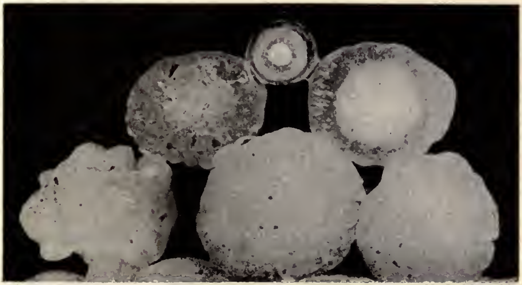

Photo. *H. J. Metcalfe.*

FIG. 51.—Hailstones collected at Richmond, Yorkshire, after a thunderstorm in July, 1893. Reduced to one-half actual size, linear measure.

by the freezing of rain-drops which have been carried up into colder regions of the atmosphere by strong currents. This action may occur several times in succession, and so produce the concentric structure of hail frequently seen. Soft hail or **graupel** falls in winter and is probably formed from snow.

Frozen vapour.—There is yet another form of atmospheric precipitate that needs a passing notice. If the temperature before dewfall should sink below the freezing-point, the moisture which would under ordinary conditions be deposited as dew takes a solid form, and is then known as **hoar-frost** (Fig. 52). Blades of grass, and other objects cooled by freely throwing off their heat into space, thus become coated with delicate icy crystals instead of dew. The hoar-frost is, in fact, not dew which has been frozen after it was formed, but moisture precipitated in a solid form from the atmosphere when the temperature is below freezing-point.

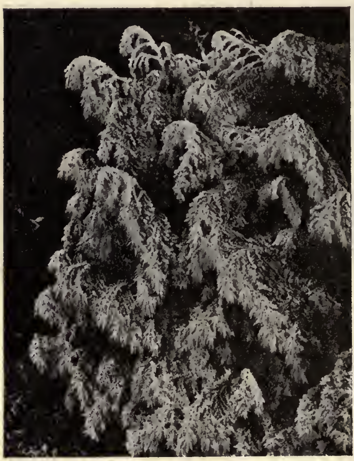

Photo. *H. W. Taunt.*

FIG. 52.—Frost on foliage.

Various forms of precipitation of moisture.—In one or other of the forms described in this and the preceding chapter, all atmospheric moisture must be precipitated. It is not however always easy, nor is it by any means necessary, to distinguish between these several forms, and they are therefore practically massed together under the general head of "rainfall." If then it is said that the rainfall of a region is twenty-six inches, what is meant is that the total quantity of atmospheric moisture precipitated within that area—adding together the rain and the snow, the hail and the dew—amounts in the course of an average year to a depth of six-and-twenty inches spread uniformly over the surface.

Invisible water vapour.—In whatever shape water may be thrown down upon the earth—whether as rain or dew, as snow or hail—it must, at one time, have existed in the state of invisible vapour diffused through the atmosphere, and not to be distinguished from the air itself. However dry the air may appear to be, it always contains more or less of this moisture. Though not recognised by the senses, its presence is readily revealed by the behaviour of certain substances which greedily absorb moisture, and are consequently said to be **hygroscopic.**[1] Oil of vitriol, or sulphuric acid, for example, is one of these hygroscopic substances. If a bottle of this corrosive liquid be left without its stopper, it will be found that, after a few hours' exposure, the bulk and weight of the liquid have sensibly increased ; indeed, a pound of oil of vitriol may in this way become two pounds in the course of a few days. This increase of weight is due to moisture absorbed from the surrounding air, and, after exposure, the acid is consequently found to be weaker. When the air is damp, the increase of weight is rapid ; when dry, the increase is but slow. Yet the liquid can never be exposed, even to the driest air, without absorbing some amount of moisture, however small.

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[1] *Hygroscopic*, from ὑγρὸς, *hugros*, moist.

It is clear, therefore, that the atmosphere must always contain aqueous vapour. Nor is it necessary to seek far for its source.

Origin of atmospheric moisture.—The damp towel on which you have just wiped your wet hands does not hang long on the towel-horse before it becomes dry again; the water left forgotten in the flower-vase a week ago has completely dried away. In such cases the water passes imperceptibly as vapour into the surrounding air by a process termed **evaporation.** It is a quiet process, very different from the noisy production of vapour during **ebullition,** or boiling; yet the same in its ultimate result. The general process of converting a liquid into a vapour, by any means whatever, may be called **vaporisation;** and two modifications of this general process may be distinguished—evaporation and ebullition. Whilst ebullition takes place only when the liquid undergoing vaporisation reaches a definite temperature, called its **boiling-point,** evaporation is a permanent process going on at all times and in all places. Every piece of open water, from the narrowest stream to the broadest sea, is constantly giving off vapour in greater or less volume. More vapour will pass into the air on a hot than on a cold day; yet, on the coldest day, the process of evaporation is simply slackened, not stopped. Even a piece of ice, exposed to air at the freezing-point, gradually diminishes in size, showing that vapour is given off from the frozen surface. A fall of snow may evaporate, just as a shower of rain is dried up, but the process is immeasurably slower. It is therefore by no means difficult to account for the water vapour in the atmosphere. And it should be remembered that, in addition to that which reaches the air by direct evaporation from river, lake, and ocean, there is a good deal of water thrown into the atmosphere as vapour by the agency of living beings, exhaled from the leaves of plants and from the lungs and skin of animals. Decay, and other chemical phenomena, likewise contribute their quota to the moisture of the atmosphere. Evaporation, however, remains the principal source of water vapour in the air.

Rate of evaporation.—It need hardly be said that the rapidity of evaporation may be materially affected in a variety of ways. If you wish to dry a damp object quickly, you place it before the fire. Temperature, then, clearly affects the rate of evaporation; the higher the temperature, the quicker the process, other conditions remaining the same. Again, the amount of loss by evaporation is greatly affected by the hygrometric state of the air; in other words, by the proportion of moisture already present in the atmosphere. If the air were perfectly dry, evaporation would be extremely rapid, and the loss correspondingly great; if, on the other hand, the air were thoroughly saturated with moisture, water exposed to it would lose nothing. As a matter of fact we rarely, if ever, experience either one or the other of these extreme conditions; but, between these extremes, there are any number of intermediate states. Every laundress knows that there are "good drying days" and bad ones. When there is but little moisture in the air the clothes dry quickly; when there is much moisture, they dry but slowly.

Humidity.—It must not be supposed that the proportion of moisture in the air is easily estimated by our sensations. True, we say that one day is dry, and another damp; but, after all, it is not so much the absolute quantity of moisture in the air as its relative humidity that determines these sensations; that is to say, it is the ratio of the vapour actually present to the amount which is capable of existing in the atmosphere at the given temperature. The higher the temperature, the greater the quantity of water which may exist in the state of vapour in the atmosphere; and consequently, on a hot day, the air may seem dry, notwithstanding it contains a large quantity of vapour, because much more might exist at that temperature. On the other hand, if the temperature be low, a small quantity of vapour may render the air damp, since it approaches nearer to the total quantity which can exist in the atmosphere at that temperature. Hence the paradox that, in summer, dry as the air may feel, it usually contains more moisture than in winter, when it is popularly said to be damper.

Evaporation affected by wind and surface.—Another condition affecting evaporation is the rapidity with which the atmosphere is renewed over the water exposed to it. On a windy day a wet pavement soon dries. Still air in contact with water soon receives as much, or nearly as much, water vapour as is capable of existing at the temperature, and thus further loss by evaporation is checked; but when the air is in motion the portions which have become charged with vapour are rapidly removed and fresh ones brought into their place, which in turn become laden with vapour and are carried away to make room for others. It need hardly be said, too, that the rapidity of loss by evaporation depends on the extent of the exposed surface of liquid. Ink dries up quickly in a wide-mouthed inkstand, but the same quantity may be preserved much longer in a narrow bottle. In fact, the vapour is derived only from the exposed surface of the liquid, and herein lies one of the great differences between evaporation and ebullition: in the rapid process of boiling, bubbles of vapour are generated throughout the mass of liquid, while, in the slow process of evaporation, the vapour is derived from the surface only.

The determination of atmospheric humidity.—Meteorologists determine the humidity of the air by instruments termed **hygrometers.**[1] The form of hygrometer now commonly used by meteorologists is known as Mason's *dry and wet bulb thermometers*, a name sufficiently descriptive of its construction. It consists, in fact, of two thermometers, placed side by side, as represented in Fig. 53; one of the instruments has its bulb free, whilst the other is covered with soft muslin, which is connected, by means of strands of cotton, with a small reservoir of distilled water: the thread constantly sucks up the liquid, just as the wick of a candle draws up the melted wax or tallow, and the bulb is in this way constantly kept moist. Whenever a body passes from the state of liquid to that of vapour, heat is absorbed: hence a little water dropped upon the hand gives rise to the sensation of cold as it evaporates; a sprinkling of *eau de Cologne*, or other liquid containing spirit of wine, produces greater cold, since it is more volatile than water and dries up much more rapidly; a little ether, again, being still more volatile, reduces the temperature yet lower. The evaporation of the water from the wet bulb therefore lowers its temperature, and the more rapid the evaporation the greater will be this difference of temperature between the wet and the dry bulbs. If the air were saturated with moisture there could be no evaporation, and consequently the two thermometers would

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[1] Instruments having names terminating in *meter* (*μέτρον*, *metron*, measure) are generally more exact in their indications than those terminated in *scope* (σκοπέω, *skopeo*, to view). Thus a *microscope* enables us to see very minute objects, whilst a *micrometer* enables us to measure them.

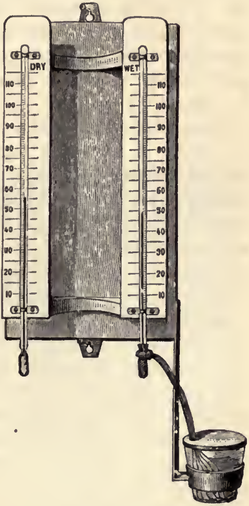

FIG. 53.—Dry and wet bulb thermometers.

stand exactly alike. When, on the other hand, the air is very dry, evaporation becomes exceedingly rapid, and the temperature of the wet bulb consequently falls much lower than that of the other. From a comparison of the temperatures shown by the two thermometers, the dew-point, relative humidity of the atmosphere, and the quantity of vapour in a given volume of air, can be determined by simple methods of calculation.

From what has been advanced in this chapter, it is evident that more or less water vapour is always to be found in the atmosphere; its presence is constant, but its proportion variable. It may perhaps be said that the air of England contains on an average something like 1½ per cent. of aqueous vapour. This vapour is intimately associated with the other constituents of the atmosphere, all being gaseous bodies existing in a state of mechanical mixture.

Natural distillation of water.—When the temperature of the atmosphere is sufficiently reduced in any given locality, the water vapour which it contains condenses as a liquid, while the other constituents retain their gaseous state. The liquid drops of water thus condensed as rain are said to be **distilled.** In fact, the process carried on in nature is precisely similar in principle to the artificial process of distillation. If it is required to distil a liquid, the liquid is evaporated in a boiler, and the vapour conducted to the condenser, where it becomes sufficiently cooled to be deposited in drops. The natural process is effected, not by boiling the water over a fire, but by the heat of the sun, which quietly steals vapour from every exposed piece of water, and the vapour thus raised into the atmosphere is ultimately condensed as drops of rain. In artificial distillation, any solid matter which happens to be dissolved in the original liquid will be left behind in the boiler, and the liquid consequently distils over in a state of purity, excepting so far as it may be contaminated by the presence of volatile matters. Just such a purification of water is effected by the natural process of distillation. The sea, which covers so large a proportion of the earth's surface, offers a vast exposure of salt water to the heat of the sun; yet the salt is left entirely behind and nothing but pure water evaporated. Fresh water is thus being constantly distilled from the briny ocean.

The waters of earth and sky.—Thus, in seeking for the sources of rivers, we are led from the springs of the earth to the rain of the heavens; and from this to the water vapour which forms part of the atmosphere; and thence to the great caldron, the ocean, whence the heat of the sun distils that vapour. The waters of the earth thus move in a continued cycle, without beginning and without end. From rain to river, from river to sea, from sea to air, and back again from air to earth—such is the circuit in which

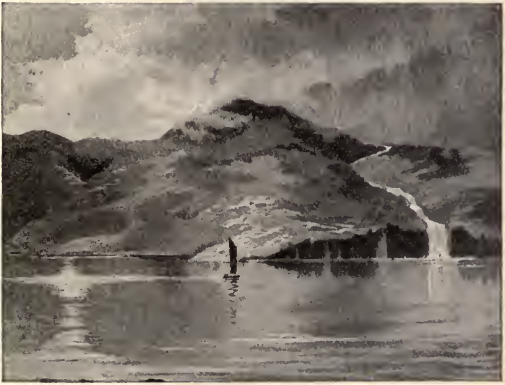

FIG. 54.—Vapour evaporated from sea or other water surfaces forms clouds, which are condensed as rain, that eventually reaches the sea through rivers.

every drop of water is compelled to circulate. The observer, who looking down upon a river watches the fresh water hurrying onward to the sea, must remember that the sea is not its resting-place, but that most of what he sees, perhaps all, will be distilled afresh and return to the earth in showers which may enter into the stream again; or swell the affluents of some river on the other side of the globe; or be secreted for untold ages in subterranean reservoirs. In the words of a wise man of old—"All the rivers run into the sea: yet the sea is not full; unto the place from whence the rivers come, thither they return again."

CHAPTER V

COMPOSITION OF THE ATMOSPHERE

Rust.—Every one is familiar with the common phenomenon of a piece of metal being eaten away by rust. A plate of polished iron or steel, for example, exposed to a moist atmosphere, soon loses its brilliancy, gradually becoming coated with a dull reddish-brown rust; and this process of rusting, once set up, may go on until every particle of the original metal has been changed in character. But let the same piece of bright metal be preserved in a vessel of pure water from which the dissolved gases have been expelled by heat, so as to avoid contact with air, and it may retain its lustre unimpaired for many years, thus suggesting that the air must be directly or indirectly connected with the phenomenon of rusting.

Active and inactive air.—Exact observations show that when a metal rusts it extracts a certain gas from the air, and undergoes an increase of weight. Air in which a metal has rusted is thus not of the same composition as ordinary air. It was not until towards the end of the eighteenth century that the compound nature of air was proved by experiments with the liquid metal mercury, commonly called quicksilver. A weighed quantity of this metal was exposed to strong heat in a vessel containing about fifty cubic inches of atmospheric air. In the course of twelve days, the shining liquid metal was completely transformed into the red rust of quicksilver. During this conversion, the air diminished in bulk by from seven to eight cubic inches, while the mercury increased in weight. On plunging a taper into the air which was left in the vessel, it was at once extinguished; and on introducing a living animal into it, the creature was suffocated. By strongly heating the mercury rust, the gas which had been extracted from the air was again released, and the mercury resumed its original state. It was obvious from this and other experiments that ordinary air consists essentially of two constituents—one of which plays an active part in producing rust, while the residual gas is inactive and unable to sustain life or combustion. The former gas received the name of **oxygen**, and the latter is known as **nitrogen**.[1]

On accurately examining a given measure of atmospheric air, it will be found to contain about one-fifth its bulk of the gas oxygen and four-fifths of nitrogen. To speak with more accuracy, 100 volumes of pure air contain 20·8 vols. of oxygen and 79·2 vols. of nitrogen. If, instead of a given *volume*, or measure, a given *weight* of air is examined, it will be found that 100 parts by weight—whether grains, ounces, or pounds—contain 23 of these parts of oxygen and 77 of nitrogen.

Properties of oxygen and nitrogen.—Before proceeding to examine more closely into the composition of atmospheric air, it may be well to note the characters of the two constituents into which it has just been seen that air may be resolved. In most of the chemical phenomena in which atmospheric air takes part, it is the oxygen which is the active agent. A glowing taper bursts into flame when plunged into oxygen. In like manner sulphur, phosphorus, charcoal, even iron-wire, will burn with great vigour in this gas, the combustible substances in all cases combining with the oxygen to form what are called **oxides.** Every act of combustion in air depends on the presence of oxygen. When a piece of charcoal burns in air, the solid disappears, with exception of a little ash; the charcoal has, in fact, combined with oxygen to form an oxide which is an invisible gas known as **carbon dioxide** or less correctly as **carbonic acid.** All our ordinary combustibles—such as coal, wood, oil, tallow, and wax—contain a large proportion of carbon; and consequently this gas is produced in considerable volume during their combustion. In like manner, the respiration of animals depends upon the presence of oxygen in the medium by which they are surrounded, whether air or water. A kind of slow combustion goes on in the body; and the oxygen, taken into the system through either lungs or gills, is in part consumed in the formation of carbon dioxide gas, which is expelled through the same organs. Oxygen is therefore as needful to support animal life as to support flame, and hence it was at one time known as **vital air.** After death, again, the matter which was once living is subject to a process of oxidation or slow combustion, by which it is converted, for the most part, into compounds which contain a larger proportion of oxygen. Oxygen is therefore essential to the maintenance of combustion, respiration, decay, and many other natural and artificial processes in daily operation. In pure oxygen, all these actions would be carried on with undue energy, and the nitrogen of the air plays an important part in tempering the activity of the oxygen with which it is associated. This nitrogen extinguishes flame and it does not support life: it kills, not by being absolutely poisonous, but simply by excluding oxygen. A fresh supply of air is therefore constantly required by a living animal, not because the nitrogen is deadly, but because the needful oxygen is absent. It should be remarked, however, that nitrogen is a most important constituent of living things, though they do not absorb this gas directly from the air.

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[1] *Nitrogen* from *nitre*, in consequence of nitrogen being a constituent of the salt called nitre or saltpetre.

Carbon dioxide.—In addition to oxygen and nitrogen, there are other gaseous bodies always present in the atmosphere. Let a saucer of clear lime-water be exposed to the air, and in a few hours the surface of the liquid will be covered with a thin pellicle of whitish matter; this is produced by something absorbed from the atmosphere, yet neither oxygen nor nitrogen produces the effect. It is due, indeed, to the presence of the gaseous substance to which reference has already been made under the name of carbon dioxide; this gas, acting on the lime-water, forms a solid carbonate of calcium, or, as it is more commonly termed, carbonate of lime; and it is this white solid substance which forms the thin skin on the surface of the water. Carbon dioxide, which is thus proved to exist in the atmosphere, is a compound of two distinct substances—carbon and oxygen. The oxygen has been already described; the **carbon** is a solid body abundantly distributed through nature, though rarely occurring in a state of purity. In its purest native form, it crystallises as the diamond; in a less pure condition it constitutes **graphite** or **black-lead**; and, in chemical combination with other substances, it forms a large proportion of coal and of all other ordinary forms of fuel. It enters largely, too, into the constitution of all living matter, whether animal or vegetable; and it is left (mixed with a greater or less proportion of other substances) when these substances are charred or imperfectly burnt, as in coke, wood-charcoal, animal-charcoal, &c.

Sources of carbon dioxide.—During all the processes of combustion, respiration, and decay, carbon combines with the oxygen of the air to form carbon dioxide, and hence this gas is constantly being poured into the atmosphere. Breathe through a straw into a glass of clear lime-water, and you will see that the liquid becomes milky as the carbon dioxide expired or breathed out from your lungs bubbles through the previously limpid liquid. If you then pour a little vinegar into the cloudy liquid, the milkiness immediately clears up, because the acid dissolves the solid white carbonate of lime which had been formed by your breath. Carbon dioxide is set free by the action of the vinegar; and, if there is enough of the solid carbonate in the lime-water, you may actually see the gas escaping in little bubbles. This bubbling, or effervescence, is likewise produced when vinegar, or almost any other acid, is poured upon an egg-shell or an oyster-shell, upon a piece of chalk or limestone or marble. All these substances consist, in truth, of carbonate of lime, and are decomposed by the acid with evolution of carbon dioxide gas. If Cleopatra ever dissolved the pearl, as the story tells, or Hannibal softened the rocks of the Alps with vinegar, a chemical decomposition was effected exactly like that just described. In consequence of the gas being thus, as it were, bound in various solid substances, its discoverer, Dr. Black, of Edinburgh, bestowed upon it the name of **fixed air.** A taper plunged into this air is at once extinguished, and an animal is suffocated. Hence the great necessity of duly renewing the air in dwelling rooms. And it is obvious that, the greater the number of people in the room, and the greater the number of gas-burners, lamps, or candles alight, the more need is there of efficient ventilation.

Amount of carbon dioxide in air.—As carbon dioxide is being constantly produced by such processes as combustion and respiration, it is clear that the proportion of this gas in the atmosphere must vary locally, being, for example, higher in a crowded space than in the open country. The average proportion of carbon dioxide in the air may be estimated at from 0·03 to 0·04 per cent. by volume; thus ten thousand gallons of air will contain between three and four gallons of carbon dioxide. Since the atmosphere is constantly receiving vast volumes of carbon dioxide from various sources, it might not unnaturally be assumed that this gas would unduly accumulate, and at length vitiate the entire bulk of the atmosphere. Such accumulation is, however, prevented by the action of living plants. To show that so small a proportion of carbonic acid in the atmosphere as 0·035 per cent. is sufficient to supply the vegetable world with its carbon, it is simply necessary to calculate the weight of this gas in the atmosphere resting on a square mile of land. The weight of air on this area is about 59,012,997,120 lbs. (or 26,345,088 tons), and the carbon dioxide which it contains weighs not less than 13,800 tons. The weight of carbon in this carbon dioxide is about 3,700 tons. The carbon dioxide, so injurious to the animal, is the source whence ordinary plants derive the whole of the carbon in their structure. Wood, for example, contains about half its weight of carbon; yet every particle of carbon in a forest of trees has been derived from the gaseous carbon dioxide invisibly distributed through the surrounding atmosphere.

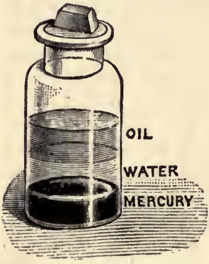

FIG. 55.—Layers of liquid of different density.

Diffusion of gases in the air.—Before leaving the subject of carbon dioxide, it should be remarked that this gas is one of great density, being in fact about half as heavy again as an equal bulk of atmospheric air. It might therefore not unfairly be assumed that the carbon dioxide in the atmosphere would tend to settle down in a stratum near the ground. If we shake up a mixture of liquids of different densities—say mercury, water, and oil—the liquids soon settle down, after agitation, in the order of their relative weights; the heavy quicksilver sinking to the bottom, and the light oil floating on the top of the water (Fig. 55). Such a separation does not however take place when *gases* of different densities are mixed.

The term **specific gravity** is used to denote the weights of equal bulks of different kinds or species of matter, compared with some known standard. Taking air as the standard of comparison, observations show that if a given bulk of atmospheric air weighs 100 pounds, then the same bulk of nitrogen weighs 97 pounds; the same volume of oxygen 110 pounds, and of carbon dioxide 152 pounds. Hence it might be assumed that the atmosphere would consist of three strata or layers (like the mixture of quicksilver, water, and oil), with the nitrogen as the top layer, and the carbon dioxide at the bottom. As a matter of fact, however, this is not the case. All gases tend to intermingle with each other, so that when different gases are mixed they soon produce a uniform mixture, in spite of differences in their relative weights; in fact, the particles of the heavy gas rise and the particles of the light gas fall until they are completely diffused through each other. In consequence of this property, the composition of the atmosphere is kept practically uniform, although local variations, within narrow limits, may be detected.

Argon and its companions.—Investigations by Lord Rayleigh and Sir William Ramsay led to the discovery of several additional gases as permanent constituents of air. Precise determinations of the density of atmospheric nitrogen, and of nitrogen prepared chemically from its compounds, showed that the natural gas was slightly heavier than the "chemical" one. This discrepancy was traced in 1894 to the presence in atmospheric nitrogen of an inactive gas nearly half as dense again as pure nitrogen; and this new constituent of air received the name of **Argon**.[1] Later researches with air from which the oxygen and nitrogen had been extracted showed that the residual gas was not composed entirely of argon, but contained other inert gases, one of which, **Helium,**[1] had previously been known to exist in the sun, and three new gases, to which the names **Neon, Krypton,** and **Xenon** were given. Five new gases have thus been proved to be permanently present in air in addition to oxygen, nitrogen, and carbon dioxide. All the new gases are remarkable for their inactive character, and they can only be separated from one another with difficulty. It is sufficient to regard the new constituents as one group of gases present in the atmosphere in the ratio of 0·937 part by volume to 100 parts of air, so that 10,000 cubic feet of air contain about 94 cubic feet of argon and its companions.

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[1] *α without, ἔργον, ergon, work.*

Variable constituents of air.—In addition to the oxygen, nitrogen, carbon dioxide, and the argon group of gases, the atmosphere always contains other constituents, but only in subordinate and variable proportions. The gas called **ammonia,** well known as the pungent gas which escapes from "spirit of hartshorn," is constantly present in the air, being indeed evolved from decomposing animal and vegetable matter. This ammonia is a compound of nitrogen with a gas called hydrogen, which will be considered in another chapter; and though it only occurs in minute proportions of ammonia in the air, it directly or indirectly furnishes to plants a large part of their nitrogen, just as the carbon dioxide gas supplies them with their carbon. Traces of **nitric acid,** the substance known commonly as **aqua-fortis,** are occasionally found in the atmosphere, especially after thunderstorms; this nitric acid readily combines with the ammonia to form nitrate of ammonia, the presence of which may frequently be detected in rain water. **Sulphuretted hydrogen,** an offensive gas given off during the putrefaction of animal and vegetable matter, may also be often found in the air; and a few other gases are sometimes present, especially in air taken from the neighbourhood of large towns. Nor should mention be omitted of the fine **dust particles** and **organic germs**, which constantly float in the atmosphere, but of which it is beyond our present purpose to speak. As to the **water vapour**, which is ever present in the air, it is unnecessary to say anything here, since the subject has already been discussed.

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[1] ἥλιος, *helios*, the sun.

Vapours and gases.—Water vapour differs from the other constituents of the atmosphere principally in the ease with which it may be condensed or liquefied. Hence it is generally called a **vapour** rather than a **gas**. Yet there is really but little distinction between the two classes of bodies; a vapour being nothing more than an easily-condensible gas. Steam, for example, is liquefied by a comparatively slight reduction of temperature, or increase of pressure, while carbon dioxide and a number of other gases require a great reduction of temperature or a great pressure, or even a combination of cold and pressure, in order to assume the liquid form; and, until recent years, several of the gases had resisted all attempts to liquefy them, and were termed **permanent gases**. Sir J. Dewar and other investigators have, however, succeeded in converting even the most refractory gases, such as oxygen, nitrogen, hydrogen, and helium into liquids, and have even reduced them to the solid state. Just as steam condenses to water, and water to ice when the conditions are favourable to these changes of state, so by the combination of pressure and extreme cold, all gases can be condensed to liquids and frozen into solids. At a temperature of about 350° F.[1] below the freezing point of water, air is converted into a clear, bluish liquid, and if this is subjected to greater cold it freezes into a solid, having nearly the same specific gravity as water. Hydrogen gas can be reduced to a clear, colourless liquid, about fourteen times lighter than an equal quantity of ice-cold water. This liquid hydrogen boils at a temperature equal to nearly 432° of frost, that is, 400° below zero on the Fahrenheit scale, and at a temperature of about 30° F. lower, it freezes into a foam-like solid, something like snow. The so-called permanent gases have thus been shown to be amenable to condensation into liquids and solids in the manner typified by the transformation of steam into water and water into ice.

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[1] The meaning of degrees of temperature is explained in Chapter VI.

Carbon dioxide and climate.—The atmosphere surrounding the earth may be compared with the glass of a green-house, which permits the bright rays of the sun to pass through, but prevents the escape of the dull radiations from the heated surfaces below it. This action is due to the carbon dioxide and water-vapour in the air; but as the proportion of the latter varies very considerably, while the quantity of the former is almost the same in the open air everywhere at all seasons, evidently the protective action of carbon dioxide gas is of prime importance. If the proportion of this gas in the atmosphere could be increased, the temperature of the ground and of the air surrounding us would be raised, and if it were diminished, all parts of the earth would become cooler. This conclusion appears astonishing when the small proportion of the gas in the atmosphere is borne in mind. In ten thousand cubic feet of pure air there are only three or four cubic feet of carbon dioxide; that is to say, only one-third per cent. of air consists of the gas to the protective qualities of which we are so much indebted. Tyndall suggested long ago that the intensely cold periods of the earth's history—Ice Ages—could be caused by variations in the proportion of carbon dioxide in the atmosphere, and more recent investigations have given support to this theory. It has been shown that a diminution of carbon dioxide to two-thirds of its present amount would probably lower the average temperature of the northern regions of the earth by at least 99° F., and hence produce the climate of the Great Ice Age. On the other hand, an increase to triple the present amount, that is, to about one per cent. in air, would probably produce a rise of temperature amounting to thirty or forty degrees, and thus convert the deserts of polar ice into regions warm enough for the development of a rich and flourishing flora, as they were in former ages. There is thus substantial reason for believing that variations of climate in the past could have been caused by slight variations in the proportion of carbon dioxide in the earth's atmosphere.

Atmospheric dust and its effects.—Dust plays an important part in the phenomena of the earth's atmosphere. If the air were perfectly free of fine particles of dust, the sky would appear as a black firmament upon which the stars would be seen shining during both day and night, and the sun would stand out as a fiercely glowing disc upon a dark background. The blue sky with which everyone who has sight is familiar, is due chiefly to the action of dust upon the rays of the sun which strike our atmosphere. The dull grey colour of the sky in the neighbourhood of large towns is caused by the presence of coarse particles of dust; but where the dust is finer and less abundant, as in the country, the sky is more frequently blue. From the summit of a mountain, the sky appears deep blue, or nearly black, because there is little dust in the air at great altitudes, most of these floating particles being at lower levels. The skies of Italy and the tropics have a deeper blue than those of Europe on account of the comparative absence of coarse water-dust produced by the condensation of water vapour upon fine particles. Around our own islands, dust particles in the air soon become larger by the condensation of moisture upon them, but in warmer countries, the moisture in the air remains in the form of vapour, and is not so frequently condensed as a liquid upon the dust. Whenever water is precipitated from the atmosphere, particles of fine dust constitute the nuclei around which the condensation of the vapour takes place. In a dust-free atmosphere, there would be no fogs, clouds, rain, or snow; when the air was saturated with moisture, water would be deposited upon whatever surfaces were in contact with it; it would trickle down from our clothes as we walked through the streets, and in a moist climate like that of the British Isles, it would be practically impossible to keep anything dry either indoors or out.

CHAPTER VI

TEMPERATURE AND PRESSURE OF THE AIR

Thermometers.—For meteorological purposes, the most important instruments are the thermometer and the barometer, which indicate the temperature and pressure of the air. Warmth and cold appeal to our sensations, so that everyone is familiar with what is meant by a change of temperature, even without being able to attach a precise significance to the term. It is, however, desirable to be able to express temperature in definite numbers, especially as human feelings are not always to be trusted in the estimation of degree of warmth or cold. A thermometer[1] provides the requisite scale by which temperature may be measured.

In its common form, the thermometer is a very simple instrument. Mercury, alcohol, or some other liquid fills a bulb at one end of a fine glass tube and part of the stem; and the other end of the tube is closed. When the liquid is warmed it expands, and so the thread of it in the fine bore of the tube becomes longer; on the other hand, when the liquid is cooled it contracts and the thread becomes shorter. The expansion and contraction of a liquid sealed up in a fine tube in this way, thus provide a means of determining changes of temperature. For purposes of comparison, however, it is necessary that the marks made on the tube or frame around it to indicate different degrees of warmth or cold should follow some standard scale of graduation.

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[1] *Thermometer*, from θερμος, *thermos*, hot; an instrument for measuring temperature.

Thermometer scales.—The thermometer commonly used in this country is graduated according to a plan introduced by Daniel Gabriel Fahrenheit, a native of Dantzic, who settled at Amsterdam in the beginning of the eighteenth century, and became famous as a thermometer maker. On the **Fahrenheit** scale the distance between the freezing and boiling points of water is divided into 180 equal parts, or degrees, and the zero or starting-point of the scale is arbitrarily placed 32 degrees below this freezing point. On the Continent another scale is commonly used, known as the **Centigrade**[1] scale, since the distance between the freezing and boiling points of water is divided into one hundred degrees. The Fahrenheit scale is used for meteorological observations in this country, but in almost all other scientific investigations the Centigrade scale is adopted. As a given temperature is indicated by different numbers on the two scales, they are distinguished by the addition of "Fahr." and "Cent." to the readings or simply by the initials F. and C (Fig. 56).

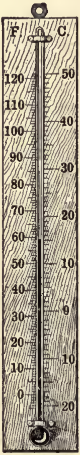

Fig. 56.—Fahrenheit (F) and Centigrade (C) divisions on a simple thermometer.

Maximum and minimum thermometers.—An ordinary thermometer indicates the temperature at the time of observation, but slightly modified forms of the instrument enable indications to be obtained of the highest or lowest temperatures since the instruments were last set. In one form of **maximum thermometer,** a small portion of the thread of mercury in the stem is separated from the rest of the liquid by a minute bubble of air. When the mercury expands on account of an increase of temperature, the detached portion is pushed forward; when, however, the temperature falls, the main body of the liquid contracts, but the detached thread is left behind and registers the highest temperature reached. By holding the instrument bulb downwards, the short thread of mercury runs down the tube, and the thermometer is then ready again to be set in a horizontal position to register the maximum temperature.

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[1] From Latin *centum*, hundred, and *gradus*, step or degree.

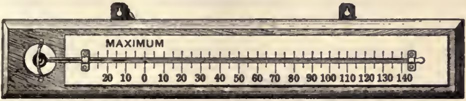

FIG. 57.—Maximum thermometer. The detached thread of mercury is pushed forward as the liquid expands and is left behind as it contracts.

In a **minimum thermometer** a short black index is enclosed in the spirit which fills the bulb and part of the stem. The index cannot break through the surface of the liquid, so it is pulled down toward the bulb when the spirit contracts as the result of a decrease in temperature, but when increased warmth causes the spirit to expand, the index is left behind to register the lowest temperature reached since the thermometer was last set. By tilting up the bulb of the

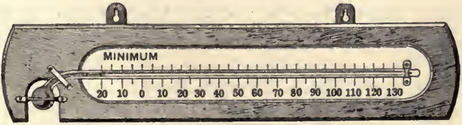

FIG. 58.—Minimum thermometer. The short index in the spirit is pulled down as the liquid contracts and is left at the lowest point.

thermometer, the index can be made to slide along the tube until it reaches the end of the spirit in the stem, and the instrument can then again be placed horizontally until another observation is made.

Self-registering thermographs.—Ordinary thermometers, and also maximum and minimum thermometers, indicate the temperature at particular instants, and do not give any information as to the general temperature throughout the day; that is to say, they do not show the duration of any degree of warmth or cold. Continuous records of temperature are, however, given by self-registering thermometers, one type of which is represented in Fig. 59. A flattened metal tube A, bent into a curve, is filled with a liquid not easily frozen, which expands when heated and contracts when cooled. In the thermometers hitherto described, space is left in the tube for the changes in volume of the liquid they contain to take place freely. If the liquid completely filled the glass tube, then a rise of temperature would cause an expansion which would burst the tube; indeed, it sometimes happens that thermometers

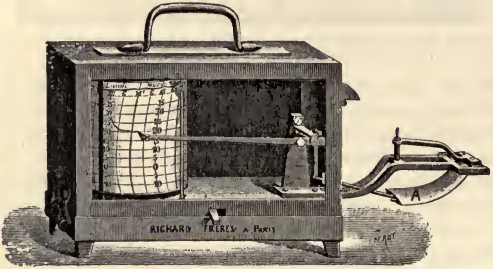

FIG. 59.—Registering thermograph. The curved tube, A, is filled with liquid, and the changes of volume of the liquid, due to variations of temperature, cause the free end of the tube to move up or down.

are fractured in this way, when the temperature exceeds that which they have been designed to indicate. The liquid which is sealed up in the tube A cannot expand freely when it becomes warmer, as it does in an ordinary thermometer; but it makes more room by distending the flattened bent tube, and thereby straightening it out slightly; and conversely, when the temperature falls and the liquid contracts, the curve of the tube increases. One end of the tube is fixed, but the other is free to move, and is connected with a lever having a pen at the other end. The pen touches a drum which is kept turning by means of clockwork inside it, and usually the rate of movement is such that the drum makes a complete turn once a week. A sheet of paper having degrees and days marked upon it is fastened around the drum every week, and the variations of temperature are registered upon it by the writing of the pen at the end of the lever connected with the flexible thermometer tube.

Temperature of the air.—To determine the temperature of the air, a thermometer must be screened from the direct action of the sun's rays. The sun shining upon the earth warms it, and the heat thus received is radiated into the air like the heat from the floor and walls of a greenhouse. The atmosphere is only slightly heated by the sun's rays which pass through it on their way to the earth's surface, but the lower layers of air surrounding us prevent the escape of the dark radiations from the warmed earth, by absorbing their heat. The temperature of the air consequently depends more on the temperature of the radiating surface of land or water than on the direct action of sunlight. The earth's surface may indeed be regarded as the radiator of heat into the air, though of course the ultimate source of the supply is the sun. On a mountain top, or high up in a balloon, the temperature of the air is very low even in summer, on account of the greater distance from the radiating surface of the earth, and the greater tenuity of the air. The sun's bright rays strike powerfully upon an observer at a great elevation, but at the same time the air is extremely cold, because it absorbs but little of their energy, and the heat which reaches the earth is confined to lower levels by the denser layers of air near the surface. Thus it comes about that although the temperature of the air differs very considerably at different parts of the earth, a few miles above the surface the temperature is always very low, over tropical as well as polar regions. The average rate at which the temperature falls in ascending from the earth is 1° F. for an increase of 300 feet in altitude, or about 20° F. per mile.

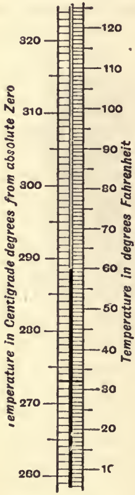
Temperature in Centigrade degrees from absolute Zero
320
310
300
290
280
270
260
120
110
100
90
80
70
60
50
40
30
20
10
Temperature in degrees Fahrenheit

FIG. 60.—Comparison of Absolute and Fahrenheit temperatures.

At this rate of decrease, the freezing-point of water would be reached at an altitude of 5,500 feet, when the temperature at the surface of the earth was 50° F., and at an altitude of 27,000 feet mercury would freeze.[1] The fall of temperature goes on until the height of the highest mountains in the world is reached, about six miles, but above this no appreciable change occurs, the temperature remaining practically the same throughout the year (Fig. 61). The layer of the atmosphere in which the temperature falls steadily with increase of altitude is called the **troposphere**,[2] and the layer above it, in which the temperature is constantly about 100° F. below the freezing-point of water, is the **stratosphere**.[2] In modern meteorology the absolute scale of temperature is often employed in recording thermometric values, all minus signs being thus avoided. On this scale, zero is 273° C. below the freezing-point of water, and 273 A. therefore

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[1] From τρόπος, *tropos*, a turning, change, and σφαῖρα, *sphaira*, a sphere.

[2] From *stratum*, spread out, and σφαῖρα, *sphaira*, a sphere.

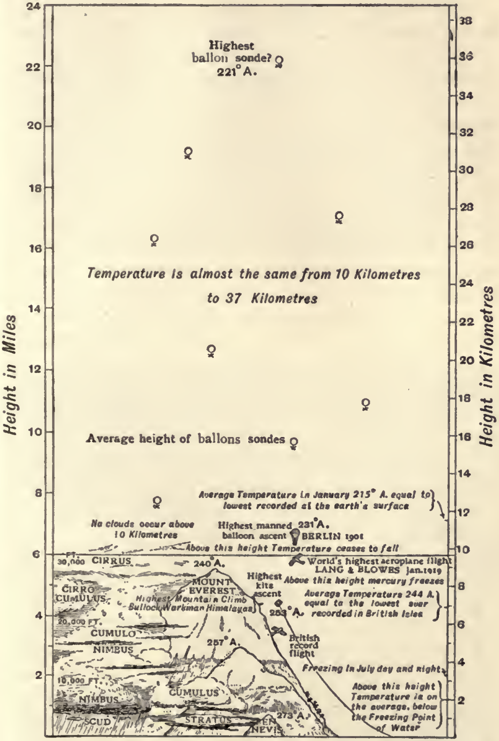

FIG. 61.—Exploration of the atmosphere. Adapted from a chart published by the Meteorological Office.

signifies 0° C. or 32° F. Equivalent values of the Absolute and the Fahrenheit scales of temperature are shown in Fig. 60.

Explorations of the upper air.—Records of the meteorological conditions at high levels are obtained at various mountain observatories, by means of self-registering instruments which run continuously for several months at a time. By using kites to carry registering meteorological instruments, facts as to the state of the atmosphere have been systematically obtained up to altitudes of about four miles. Balloons carrying observers have twice enabled personal observations to be made at an altitude of about six miles, which is higher than the loftiest mountain, and small unmanned or **free balloons,** called **ballon sondes,** carrying self-registering instruments, have permitted meteorological information to be obtained up to an altitude of twenty miles or more. When these balloons lose their buoyancy, they fall to the earth, and the registers they bear are forwarded by the finders to the address given upon them, with a notification of the place of descent. To determine the direction and velocity of the wind at various levels, small **pilot balloons** are sent up in clear weather and their tracks are followed. The information thus gained is of great value, not only for meteorology, but also for aircraft purposes.

Variations of temperature.—From the results just described, it is clear that by rising above any place, regions of lower temperature are attained, similar to those usually experienced in moving towards polar regions. But the temperature of the air at any place outside the tropics differs in the course of the day and year. The copy of a register of temperature reproduced in Fig. 62 shows the rise during the day and fall at night; and the diagram in Fig. 63 exhibits the annual variations near the equator and at London. It will be noticed that at Barbados the temperature varies but slightly throughout the year; there are practically no seasonal changes, such as are experienced in countries like England, situated in temperate latitudes.

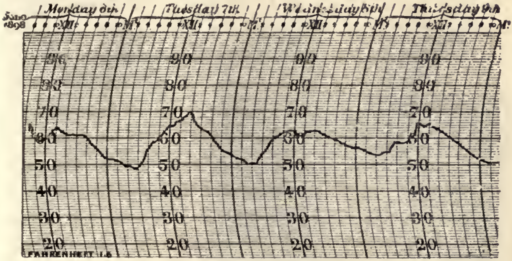

FIG. 62.—Part of the register of a Richard thermograph, showing diurnal range of temperature in June, 1898, at the "British Rainfall" Observatory, London.

Land and water temperatures.—The soil in northern Europe reaches its highest temperature for the

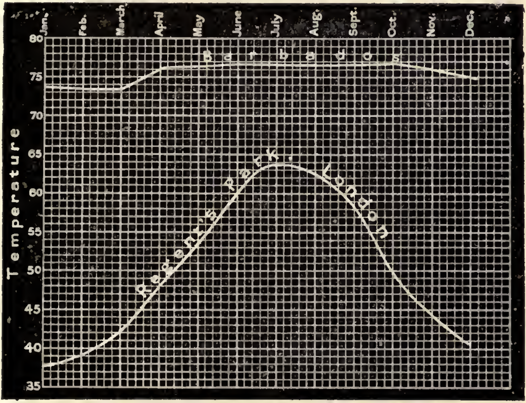

FIG. 63.—Annual variations of temperature at Barbados and London.

year in September, and its lowest in March. Air and water are warmest and coldest a month earlier than the soil, that is, in August and February. Records obtained in many places have shown that the Baltic takes up during summer from twenty to thirty times as much heat as the land, and the North Sea from thirty to forty times. The sea stores up this excess of heat; its surface does not get hot, so that little warmth is imparted to the air by the water in summer, but during the cold season heat is replenished from below. On land, however, the heat of the sun does not penetrate in this way. The soil becomes hot on warm days and in warm seasons, and gives off much heat to the neighbouring air at the time, but it saves up little heat and cools rapidly, with the result that it has no store of heat to draw upon in the winter.

British temperatures.—There is a difference of six degrees between the mean annual temperatures of the southernmost and northernmost parts of our islands; the average temperature of the year in Cornwall being 52° F., and that of the Shetland Isles 46° F. The mean annual temperature does not, however, decrease uniformly in passing from south to north, as may be seen by an examination of Fig. 64, in which the white lines connect places having the same mean annual temperature, and are termed **isothermal lines** or **isotherms.** It will be noticed that the mean temperature at nearly every place on the west coast is greater than at a place in the same latitude on the east coast. Anglesey has the same mean temperature, 50° F., as the mouth of the Thames, and Skye as the mouth of the Tees, though both places on the west side are much farther north than the places on the east with which they are compared. The difference is due to the comparatively warm south west winds, which are more frequent in our islands than winds from other directions. In the winter months, these winds and the Atlantic water they bring with them from warmer regions maintain the temperature of the British Isles much in excess of the degree due to latitude and season. But for this influence, the mean temperature of London in the middle of winter would be 22° F. instead of about 38° F.; that is to say, the winter would be like that experienced in the north-west of Iceland, and the winter of Edinburgh would be as severe as that of the south of Greenland.[1]

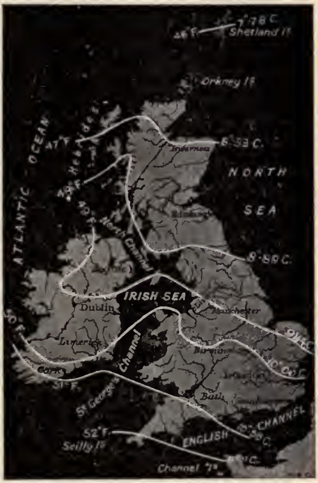

FIG. 64.—Mean annual isotherms for the British Isles. (Buchan.)

At most places in the British Isles, the lowest temperature occurs usually in January, but a few, as, for instance, Ilfracombe and Seathwaite, have their minimum in February. Practically all inland places attain their highest annual temperatures in July; and with few exceptions places on the coast have their maximum in August. From observations extending over many years, it appears that the mean annual temperature of London is about 50° F., with a mean minimum temperature of 38° F. in January, and a mean maximum of 64° F. in July. The seasonal range of temperature represented by the interval between these two limits may thus be taken to be about 26° F.

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[1] "The Mean Atmospheric Pressure and Temperature of the British Islands." By Dr. Alexander Buchan, F.R.S. *Journal of the Scottish Meteorological Society.* Third Series, Nos. XIII. and XIV. 1898.

Distribution of isothermal lines.—An examination of isothermal lines of the world, connecting places which have the same mean annual temperature, shows clearly that other conditions beside distance from the equator determine the temperature of a place. If latitude were the only determining influence, the temperature of the air would decrease at a continuous and steady rate in proceeding from the equator toward the poles, but the chart reproduced in Fig. 65 shows that this is not the case. Notice, for instance, that the belt of greatest heat, the median line of which is called the **heat equator**, does not lie as a band of uniform width extending equally to the north and south, but is an irregular strip, with its central line slightly north of the geographical equator. This is due to the greater amount of land in the northern than in the southern hemisphere. The irregular distribution of land and water is in fact responsible for the forms of the isothermal lines. Far south, where ocean water encircles the earth without interruption, the isotherms follow a comparatively regular course; but mark how they are curved, now north, now south, where land and water meet in the northern hemisphere.

A comparison of isothermal maps for January and July is even more instructive than the examination of a map showing mean annual isotherms. The belt of greatest heat lies much farther north in summer than in winter, and all the other isotherms are similarly affected. Toward this irregular zone of warm air there is a general movement of surface winds both from the north and south. The heated air rises and flows away as currents in the upper levels of the atmosphere, and as these cool they settle down to the earth's surface to blow as relatively warm winds.

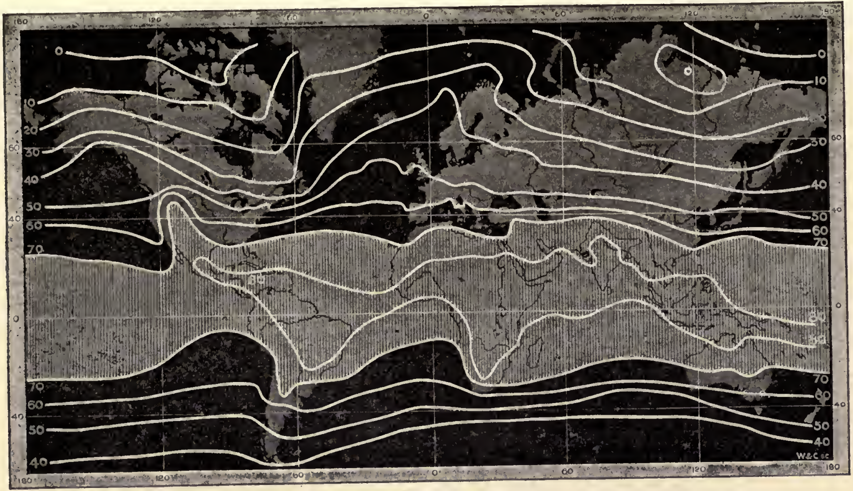

FIG. 65.—Mean annual isothermal lines. The belt of tropical temperature is shaded.

Weight of air.—When a strong wind blows, we are given unmistakable evidence of the real existence of the air around us. Everything that can exert force in this way must possess weight; though, in the case of gases and vapours, this weight is necessarily small compared with that of the same bulk of liquid or solid matter. Atmospheric air is, in fact, about 800 times lighter than an equal bulk of water, and as much as 11,000 times lighter than an equal volume of quicksilver. Yet the weight of air, small as it seems, amounts to something considerable when we are dealing with a large bulk, or even with such a quantity as is contained in an ordinary dwelling-room. It is found by actual weighing that 100 cubic inches of air, under ordinary conditions, weigh about 31 grains; in other words, it requires 13 cubic feet of air to weigh a pound avoirdupois. Suppose, then, that we have a room measuring 10 feet long, 10 feet wide, and 10 feet high: this will contain 1,000 cubic feet of air, and the weight of this air will be about 77 pounds. But the room just taken is a very small one, and if the calculation be extended to a large public building it will be found that the air which it contains weighs more than is commonly imagined. Thus Westminster Hall has a length of 290 feet, a width of 68 feet, and a height of 110 feet; its contents must therefore be 2,169,200 cubic feet, and the weight of the air in this hall reaches the enormous amount of nearly 75 *tons!*

Atmospheric pressure.—Since air possesses weight, it necessarily presses upon any object exposed to its influence. The atmosphere forms an ocean of air bathing the entire earth; and, on the floor of this ocean, man, in common with all terrestrial beings, has his dwelling. Everything around us on the earth's surface must therefore bear the pressure of the air above, just as anything on the bed of the ocean is pressed upon by the superincumbent water. The depth, or rather the height, of this aerial sea has never been determined, but there are reasons for believing that the atmosphere extends to at least 100 miles upwards from the earth's surface. Hence it is clear that all terrestrial objects must be subjected to enormous pressure. The roof of a house, for example, has to bear the pressure of a column of air resting upon its surface and extending upwards to the limit of the atmosphere. Now it is found that our atmosphere exerts on the average a pressure of nearly 15 lbs. (14·73 lbs.) on every exposed square inch of surface. The roof is consequently pressed upon by a weight of many tons. Yet the most delicate structure may be freely exposed to the atmosphere without the slightest danger of being crushed. This arises from the fact that **fluids**[1] transmit pressure in a manner entirely different from that in which it is transmitted by solid bodies.

Pressure in all directions.—A solid presses downwards only, but a fluid presses equally in all directions, upwards as well as downwards. The air in a room, for instance, presses on the ceiling not less than on the floor; and on each of the walls not less than on the ceiling. Under ordinary conditions, therefore, the atmosphere has no power to crush, because its pressure downwards is exactly neutralised by its pressure upwards. Extend your hand, and you feel no pressure, though it is certain that every square inch of its surface bears a pressure of nearly 15 lbs., and the entire hand must therefore sustain a very large total pressure; but the weight upon the upper surface is counteracted by the upward pressure of the air on the under surface, the two equal and opposite pressures neutralising each other. Nor is there any tendency for the hand to be crushed between these opposing pressures, for the air and other fluids in the vessels and various tissues of the body press equally in all directions, so that any pressure from without is perfectly counterbalanced by an equal pressure from within. The thinnest soap-bubble sails safely through the air, though its outer surface must sustain a pressure of many pounds; for the air within the bubble presses just as forcibly against the inner wall, and thus resists the external atmospheric pressure, and effectually prevents collapse. In the common toy known as "Jack in the Box" a spring inside the figure presses upwards against the lid when tightly shut down; and in like manner the walls of a closed vessel containing air are pressed outwards by the elastic force of the confined air. If the air be removed from the interior of a closed vessel, so as to leave a space altogether empty or vacuous, the pressure of the external atmosphere becomes at once evident, since it is no longer counterbalanced by any force from within; a thin glass vessel, for example, may easily be shattered by sucking the air from its interior.

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[1] *Fluid*, from *fluo*, I flow; a term embracing both *liquids* and *gases* or *vapours*, since the particles of both classes of bodies flow freely over each other.

Amount of atmospheric pressure.—It is easy to measure the amount of this atmospheric pressure by a simple experiment, first made in 1643 by an Italian philosopher named Torricelli. Take a glass tube, rather more than 30 inches in length, closed at one end and open at the other; fill this tube with quicksilver, and closing the open end with the thumb, as shown in the right-hand tube in Fig. 66, invert it in a basin of mercury so that the open end may dip beneath the liquid. It will then be found that the mercury falls for a short distance in the tube, but a column about 30 inches in length remains suspended, as shown in the left-hand tube in the figure. Torricelli argued that this column must be supported by the pressure of the external atmosphere on the surface of the mercury; the downward pressure of the column of mercury being exactly balanced by the upward pressure of the atmosphere transmitted through the quicksilver.

Indeed, if we admit air by making a hole in the top of the tube, the column immediately falls, since it is then pressed down by the atmosphere above; but when the tube is closed there is no atmospheric pressure on the top within the tube, for the space above the column of mercury is completely empty, or rather contains only mercury vapour, whence it is called the **Torricellian vacuum.** Since the column of mercury inside is balanced by the atmosphere without, it follows that if we know the weight of the mercury we know also the weight of a column of air standing on a similar base and extending upwards to the extreme limit of the atmosphere. Now a column of mercury 30 inches long, in a tube of one square inch in sectional area, weighs about 15 lbs.; hence it is found, as before stated, that the weight or pressure of the atmosphere is about 15 lbs. on every square inch.

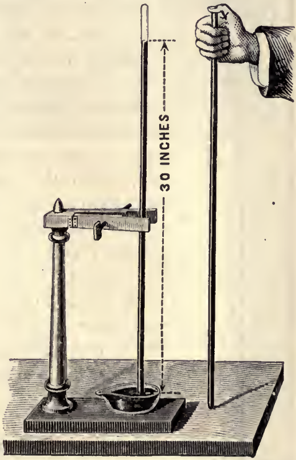

FIG. 66.—Construction of a barometer.

What a barometer measures.—If instead of using a dense liquid, like mercury, a lighter one, such as water, is employed, it would naturally be expected that the column required to balance the weight of the external atmosphere would be proportionally longer. As a matter of fact it is found that, when water is used, the suspended column is something like 33 feet in length: in other words, as water is about $13\frac{1}{2}$ times lighter than mercury, bulk for bulk, the column of water will be about $13\frac{1}{2}$ times longer than the mercurial column. It was, indeed, by observing a body of water raised in the suction-pipe of a pump at Florence, that Torricelli was led to his experiment with quicksilver. In working a common pump, air is sucked out of the tube communicating with the source of water below, and the pressure of the atmosphere then forces the water up the pipe in order to supply the place of the air which has been removed. But, when the pipe reaches a length of more than about 30 feet, the column of water which it contains balances the atmospheric pressure, and consequently if the tube be longer than this no more water rises, and the pump ceases to act. In seeking to find out why water cannot rise higher Torricelli was led to make the experiment to which reference has been made, and to construct the instrument represented in Fig. 66. It is called a **Barometer.**[1]

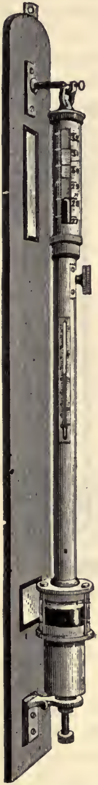

FIG. 67.—A standard barometer.

Aneroid barometers.—Various forms have been given to the barometer, but with the exception of the **aneroid**[2]—an entirely distinct instrument, in which the pressure of the atmosphere acts upon a thin elastic metal case, the movements of which are transmitted to a dial, or lever—they all depend on the same principle, namely, that of causing a column of liquid to be balanced against the weight of the atmosphere. Almost any liquid may be employed, but as a matter of convenience, mercury is the only substance in common use.

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[1] *Barometer*, from *βάρος*, *baros*, weight, and *μετρον*, *metron*, measure; an instrument for measuring the weight of the atmosphere.

[2] *Aneroid*, from the privative *ἀ*, and *νηρός*, *neros*, moist.

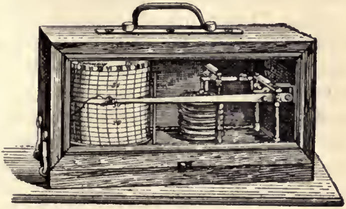

FIG. 68.—Registering aneroid barometer

Though an aneroid barometer cannot be depended upon over long periods, it is conveniently used as a self-recording instrument. Several shallow metal boxes with thin flexible lids are arranged as shown in the centre of Fig. 68. These boxes are entirely or partially exhausted of air, so that any increase of atmospheric pressure causes the flexible lid to yield slightly inwards, while a decrease causes the lid to bend outwards. The movement of the lids is communicated to a lever, having at one end a pen or pencil which is continually in contact with a revolving drum, or is pressed against such a drum by clockwork at intervals of an hour or so.

Use of the barometer.—As the pressure of the atmosphere in any given locality varies from day to day, and even from hour to hour, the indication of a barometer is subject to corresponding fluctuations. The great use of the barometer, in fact, is to show these changes of atmospheric pressure—changes which are of vast importance to the meteorologist, since they are related to general changes in the weather. Not that the barometer forms a "weather-glass" as popularly understood: it does not indicate absolutely the character of the forthcoming weather, and the indications given on the dial of common instruments are scarcely of any scientific value. But still, the changes in atmospheric pressure point to changes in the winds; and these are the prime movers in effecting changes in our weather. Hence the readings of the barometer form the chief element in the weather-charts and reports issued by most daily papers, and the forecasts of weather obtained from the Meteorological Office.

Weather reports.—The weather forecasts issued by the Meteorological Office are based upon observations made at 8 a.m. and 6 p.m. every day at a number of stations in the British Isles, chiefly on the coast, and at stations on the Continent of Europe. From each of these stations the Meteorological Office receives a telegraphic message recording the readings of the barometer, dry and wet bulb thermometers, maximum and minimum thermometers, rainfall, and in some cases sunshine, with estimates of the direction and force of the wind, and reports of the weather and state of the sea. The information thus received is tabulated and charted every morning and evening, and from this material

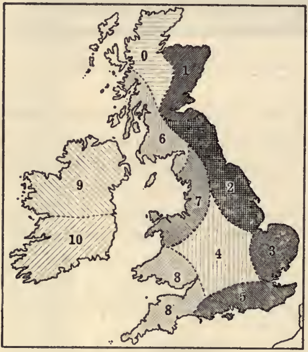

FIG. 39.—Divisions of the British Isles for weather forecasts:—

0. Scotland, North.
1. Scotland, East.
2. England, N.E.
3. England, East.
4. Midland Counties.
5 England, South, and English Channel.
6. Scotland, West, with Isle of Man.
7. England, N.W., with North Wales.
8. England, S.W., with South Wales.
9. Ireland, North.
10. Ireland, South.

forecasts of the weather are drawn up for the twenty-four hours following the next noon or midnight, as the case may be. For the purposes of these forecasts, the British Isles are divided into eleven districts, as indicated in the accompanying map (Fig. 69). Many newspapers print the forecasts issued on the previous evening for the twenty-four hours from midnight to midnight, but the latest information as to weather in any district, or the latest forecast, will be sent by the Meteorological Office to any address in reply to a prepaid telegram.

Parts of the Daily Weather Reports issued by the Meteorological Office are published in the daily newspapers with sufficient explanation to enable them to be easily understood. Two charts from the Weather Reports for September 9 and 10, 1903, are reproduced in Fig. 70.

Standard pressure.—It should be explained that, in all weather charts of the kind here represented, the actual reading of the barometer has been reduced to certain standards, in order to secure the requisite uniformity for comparison. These corrections refer to the height at which the instrument is placed, and to the temperature at which the reading is taken. It is obvious that the barometer will be affected by its height above the sea-level; for, as we ascend, we leave a portion of the atmosphere below us, and, consequently, the pressure is lessened and the mercury falls. Hence a barometer at the top of a house always reads lower than one on the basement; the instrument is, indeed, often used for the approximate measurement of heights. Barometric readings from different stations cannot therefore be compared together until we know at what elevations the instruments are situated; one observer may live on high ground and another on low, one may have his barometer upstairs and another downstairs. Hence it has come to be understood that all barometric readings shall be reduced to what they would be if the instrument were at the sea-level, which gives, of course, a fixed datum line. Then, again, the barometer needs correction for temperature. Mercury, in common with other liquids, expands by heat, and expands much more than the glass tube which holds it; hence the barometer will rise on a hot day and fall on a cold day, although the atmospheric pressure may not have changed. It is essential, therefore, that all barometric readings should be reduced to the same temperature, and the standard taken for this purpose is the freezing-point of water, or 32° of Fahrenheit's thermometer. All the figures given in the weather charts which appear in the daily newspapers are consequently reduced to sea-level and to 32° F.

Pressure charts.—The most striking feature in each of the accompanying charts is a series of curved lines, which are called **isobars.**[1] An isobar is simply a line connecting all those places which have, at a given time, the same barometric pressure. Thus the isobaric line, marked 30·0 in the chart for September 9, sweeps in a bold curve from the south of Ireland through France. At all points along this course the barometer stood at 30·0 inches, as indicated by the figures at one extremity of the curve. The next isobar, which follows a nearly parallel but more northerly course, is marked 29·9 inches, so that between the two lines there is a difference of pressure equal to that of one-tenth of an inch of mercury. Another isobar stretches across the north of Ireland and south-west England, and indicates a pressure of 29·8 inches; and there are several other similar curves indicating pressures differing by one-tenth of an inch until the oval curve along which the pressure is 29·3 inches is reached. The chart therefore shows at a glance the distribution of atmospheric pressure over the area represented, and from this we can learn a good deal about the character of the winds. Between two successive isobars there is a difference of pressure represented by one-tenth of an inch of mercury, and the distance between these two lines gives us the gradient. This term is familiar enough in engineering; if a railroad, for example, rises one foot for every 100 feet of distance, the line is said to have a **gradient** of 1 in 100. The gradient is therefore the engineer's expression for the slope of the ground; in like manner it is the meteorologist's expression for what has been called the slope of the atmosphere. Only, in talking about meteorological gradients, it must be borne in mind that the vertical scale is measured in hundredths of an inch of barometric pressure, while the horizontal scale is measured in miles of distance, the unit being one degree, or 60 nautical miles. Hence a gradient of 4 means that over a distance of 60 nautical miles the barometer rises $\frac{4}{100}$ or $\frac{1}{25}$ of an inch. When, as in the accompanying charts for September 9 and 10, the isobars run close together, it shows that the gradient is high, and therefore the winds are strong; if they are wide apart the

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[1] *Isobar*, from ἴσος, *isos*, equal; and βάρος, *baros*, weight.

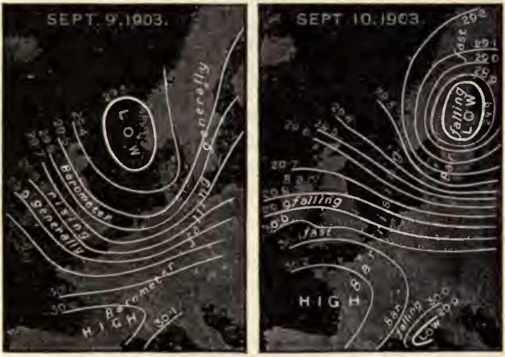

FIG. 70.—Pressure charts from the Daily Weather Reports of the Meteorological Office for 8 a.m. on September 9 and 10, 1903.

gradient is low, and the winds are light. The rule is similar to that for judging the slope of ground from contour lines, as described in the first chapter.

Barometer and wind.—Although much may be learnt about winds by studying the isobaric lines, it must not be supposed that the air blows *directly* from regions of high pressure to those of low pressure. A rule known as Prof. Buys Ballot's law, which gives the exact relation of winds to pressure, may be thus expressed: "Stand with your back to the wind, and the barometer will be lower on your left hand than on your right." Thus stated, however, the law is true only for the northern hemisphere; in the southern it will be reversed, the barometer being lower on the right hand than on the left. The same principle may be enunciated in another form. If you stand with the high barometer to your right and the low barometer to your left, the wind will blow on your back. The course of the isobars in the charts therefore indicates the *direction* of the wind, just as the distances between these lines indicate its *strength.*

Cyclones and anti-cyclones.—Storm warnings and weather forecasts are based upon meteorological information collected from many places and charted in the manner shown in the figures. When the observations reported by telegraph from the various stations are plotted upon a map in this way, they are usually found to enclose an area where the barometer reading is low or high, indicating a condition of low or high atmospheric pressure. When an area of low pressure is enclosed by the isobars as indicated on the charts in Fig. 70, the system constitutes a **cyclone.** If the barometric pressure at the centre of the cyclone is very low, and the isobars are close together, strong winds or gales are experienced, and in general a cyclonic system brings rough and squally weather with rain or snow. Where the central area is a region of high barometric pressure, as illustrated at the bottom of the two charts, the conditions of an **anti-cyclone** prevail. The general circulation of the wind in this case is in the same direction as that in which the hands of a watch or clock move, and is thus the reverse of what occurs in a cyclonic system, in which the winds circulate in a left-handed or counter-clockwise fashion. Other characteristics of an anti-cyclone are opposed to those of a cyclone. The weather is usually quiet and dry, hot in summer, cold in winter, and when the isobars are far apart there is a calm, which may last for weeks, whereas cyclones move rapidly across a country, and the unsettled weather brought by them is not often of long duration.

Storm warnings.—If the approximate rate is known at which the central depression of a cyclonic system is travelling, and also the direction of motion, the time of arrival at a spot toward which it is moving may be predicted. Over a large country like the United States a cyclonic system can be tracked from the Rocky Mountains until it passes into the Atlantic on the east coast, so it is often possible to predict with confidence when a storm will pass over a part of the country toward which it is travelling. But there are no stations to the west of the British Isles to give us warning of the approach of an atmospheric disturbance; moreover, when a depression appears it is difficult to know its direction and speed, or whether it will become more pronounced or will break up.

A gale.—Consider, for instance, the violent storm which travelled over the central portion of the British Isles on September 10, 1903, causing enormous damage in its passage over sea and land. A depression was found to be approaching Ireland on the morning of September 10, and at 6 p.m. on the same evening the disturbance reached the Irish Sea, having advanced at the rate of fifty miles an hour, and a few hours later it had spread over nearly the whole of the British Isles. So rapid was the rate of progression that at 8 a.m. on the next day, September 11, the centre of the storm had reached the north of Holland, as is shown in one of the charts reproduced in Fig. 71. During the passage of this gale, the barometric pressure fell at the unusual rate of more than one-tenth of an inch per hour, and near the mouth of the English Channel the velocity of the wind reached nearly seventy miles an hour. A depression of such a decided nature is evidence of an unmistakably bad character, and if the weather forecaster had to deal with disturbances of this kind alone his task would be easier than at present. But there are many secondary depressions and other varieties of distribution of atmospheric pressure to complicate meteorological considerations, so that when indications of the approach of a depression are first observed it is impossible to state confidently whether it is primary or secondary, large or

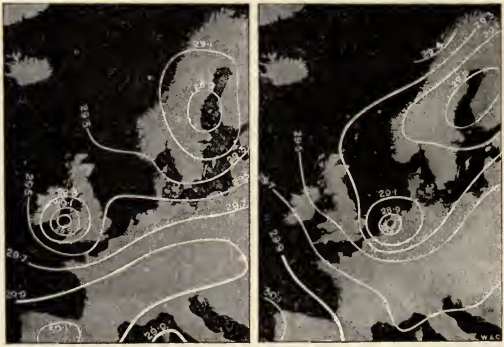

FIG. 71.—Pressure charts for Sept. 10, 1903, 6 p.m., and Sept. 11, 1903, 8 a.m. From the Weekly Weather Report of the Meteorological Office.

small, deep or shallow, or whether the good or the bad elements will obtain the mastery.

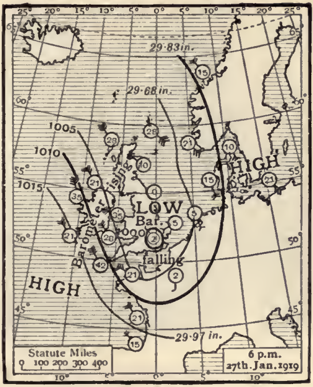

FIG. 72.—Adapted from the weather chart issued by the Meteorological Office on January 27, 1919.

New weather charts.—Since 1914 a new system of denoting atmospheric pressure has been used by the Meteorological Office. The unit is the **bar**; and it is equal to an air-pressure of 29·531 inches of mercury in a barometer: one-thousandth part of the unit is a **millibar**, which corresponds to about three-hundredths of an inch on the ordinary scale. The chart from the *Times* of January 28, 1919, reproduced in Fig. 72, shows isobars marked in millibars at one end and corresponding inches of mercury at the other. The interval between two isobars is five millibars. Equivalent values on the two scales are shown in Fig. 73. The arrows on the chart indicate the strength of the wind near the ground by the number of feathers upon them, on a scale in which a single feather

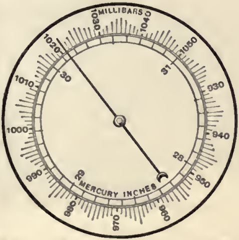

FIG. 73.—Scales of inches and millibars on an aneroid barometer.

signifies a mere breath of wind and twelve feathers a hurricane. The approximate wind-speed in miles per hour is shown within the small circles.

Investigations in recent years suggest that all the cyclonic and other movements recorded upon weather maps are controlled by changes of pressure at a height of about five and a half miles.[1]

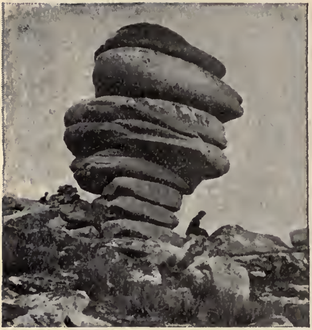

Photo. *G. W. Wilson.*

FIG. 74.—The Cheese Wring, Cornwall, showing the effect of wind and weather on granite.

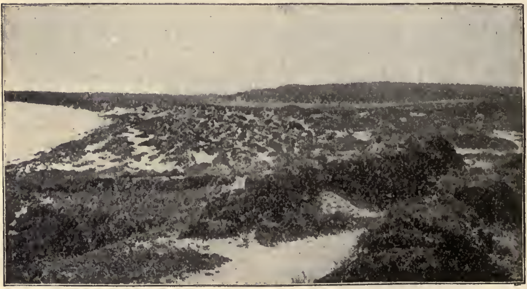

FIG. 75.—Sand-dunes between sea and marsh, Penally, South Wales. From Lord Avebury's *Scenery of England.*

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[1] For an instructive account of the whole subject, see "The Weather Map," by Sir Napier Shaw, published by the Meteorological Office, price 4*d*.

Work of wind.—The surfaces of rock are exposed to all the variations of atmospheric condition described in this and the previous chapter, and are corroded by these influences, the general result of this aërial action being termed **weathering.** Violent gales not only uproot trees and do other damage on land and sea, but also displace rocks loosened in other ways. In our country rocks are worn down into fine particles chiefly by the action of rain, frost, and running water; but when the material thus produced is loose enough, the wind shakes it down to lower levels or carries it away. Even such hard rocks as granite are continually being disintegrated by weathering, the lines of weakness being the joints or fissures which traverse most rocks. The wind, often assisted by the particles of sand which it carries, removes the crumbled rock, and in time carves out such fantastic forms as the granite **tors** of Devon

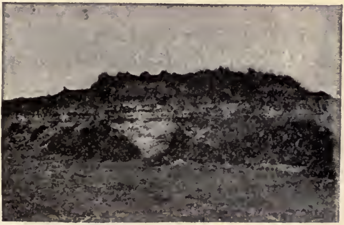
FIG. 76.—Sand-dunes, Leasowe, Cheshire, showing stratified structure of the accumulated sand. From a photograph by Mr. C. A. Defieux.

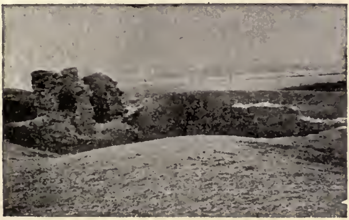
FIG. 77.—Constantine's Church, near Trevose Head, North Cornwall, surrounded by sand-dunes. Reproduced, by kind permission, from a photograph by Mr. A. E. Murray.

and Cornwall (Fig. 74). On shores where extensive stretches of sands are left dry, the action of wind in modifying the surface of the land is well displayed. Even in our own country very remarkable results due to the removal and deposit of sand by wind are to be seen. Sand-hills or **sand-dunes** (Fig. 75) are produced by the accumulation of the wind-borne fragments, the deposit sometimes showing a stratified structure (Fig. 76) in which the layers accumulated until it was uncovered in 1835. On the western border of Europe, blown sand occupies nearly half the coast from the Pyrenees to the Baltic, and it advances at the rate of three to twenty-four feet in a year. Many fertile fields and houses of once populous districts have been overwhelmed by this advancing sand. In North America, on the shores of Lake Michigan, the dunes reach a height of 100 to 200 feet; and swamps, forests, and even low hills have been buried by the onward march of the wind-driven sand.

CHAPTER VII

THE COMPOSITION OF PURE AND NATURAL WATERS

Nature of water.—Had the question, "What is water?" been asked a little more than a century ago, the wisest chemist of the day could have returned no answer, save that which might have been given thousands of years earlier. He would have replied, in short, that water, like air, is one of the elementary principles of Nature. And yet there had not been altogether wanting observations which suggested that, after all, water might not be a simple substance. Thus the sagacity of Sir Isaac Newton led him to believe that water might consist of ingredients which were unlike each other, and that one or more of these might be inflammable. Such conjectures, however, could not be verified until considerable advance had been made in chemical science; and it was reserved for the chemists of the last quarter of the eighteenth century, soon after they had determined the composition of atmospheric air, to demonstrate the true chemical constitution of water.

Constituents of pure water.—It was found in the year 1800 that when a current of electricity is passed through water, bubbles of gas are produced, owing to the decomposition of the liquid into its constituent elements. The electricity, in fact, splits the water into two distinct kinds of matter, both gaseous; one gas—**oxygen**—appearing at the pole where the current enters, and the other gas—**hydrogen**[1] —where it leaves the water. The longer the current of electricity is allowed to pass, the more oxygen and hydrogen are generated; and, if the current could be continued for a sufficient time, all the water might be thus decomposed, and resolved into these two gases. This experiment, therefore, shows that pure water consists of oxygen and hydrogen. Moreover, a careful examination of the quantity of gas generated shows that twice as much hydrogen as oxygen is produced. If a cubic inch of oxygen is generated, two cubic inches of hydrogen will be obtained in the same time; and it is found that these proportions are exactly preserved wherever and whenever water is subjected to decomposition. It is seen, then, not only that water is composed of the two substances, oxygen and hydrogen, but that they exist in water in a constant proportion; so that, when they are set free and assume the gaseous state, there is always one volume of oxygen to two volumes of hydrogen gas.

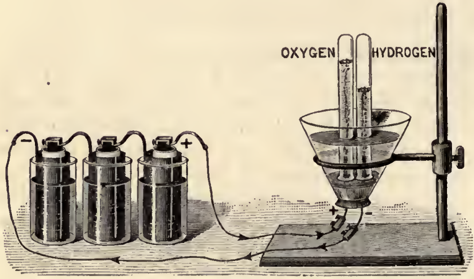

FIG. 78.—Apparatus for decomposing water into its constituent elements—oxygen and hydrogen—by the electric current.

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[1] *Hydrogen*, from ὕδωρ, *hudor*, water, γεννάω, *gennao*, to produce.

Physical and chemical changes.—The experiment just described gives a clear insight into the essential constitution of water. None of the changes which were described in preceding chapters had in any way affected this constitution. Water may be frozen, for example, into solid ice, but the ice will consist of oxygen and hydrogen in exactly the same proportions as in the liquid water. The water may be boiled and become the invisible gas, steam, but the steam will consist of oxygen and hydrogen in exactly the same proportions as in the water or in the ice. It will thus be understood that the **physical properties** of matter may be altered without affecting its deeper **chemical constitution.** The three conditions of a solid, a liquid, and a gas—represented respectively by ice, water, and steam—are physical states dependent mainly on temperature, and the chemical constitution of steam remains unaltered by a temperature far above the boiling point, while that of ice is not affected by any known degree of cold.

Elements and compounds.—Oxygen and hydrogen being obtained by the decomposition of water, it may naturally be inquired whether these substances cannot in turn be decomposed. To this question it can be simply replied that the most skilful chemists have hitherto failed to effect such decomposition. They have found it impossible to obtain from oxygen anything but oxygen, or from hydrogen anything but hydrogen ; and in the present state of our knowledge, these bodies are consequently regarded as **elementary** or **simple substances.** Nitrogen, which was obtained from the atmosphere (p. 80), is another of these elements ; and altogether chemists are acquainted with not fewer than seventy-five of these simple bodies, a large proportion of which are metals. Everything existing around us is consequently regarded by chemists either as an **element** or as a **compound**. Oxygen, hydrogen, and nitrogen are elements ; carbon dioxide, ammonia, and water are compounds. These compounds generally have properties very different from those of their constituents; thus, in none of its physical forms does water possess the properties of either hydrogen or oxygen; even as steam, it differs markedly from these, being neither combustible like the one, nor a supporter of combustion, like the other. When two substances are simply mixed together, without entering into chemical combination, they produce a mixture, having properties which partake of those of its components. Thus, if four volumes of nitrogen are mixed with one volume of oxygen, a mixture is obtained which resembles atmospheric air, and is precisely what we should expect to produce; the activity of the oxygen being tempered by dilution with nitrogen. For this and other reasons, chemists believe that atmospheric air is a **mechanical mixture** of gases; whilst water is a true **chemical compound.**

Composition of water by weight.—It has been stated that when water is decomposed the volume of hydrogen obtained is twice as much as that of oxygen. Now oxygen is sixteen times heavier than hydrogen, taking bulk for bulk; if therefore we obtained from a given quantity of water a volume of oxygen that weighed 16 grains, then we should find an equal volume of hydrogen weighed 1 grain; but, as a matter of fact, in the experiment described on p. 122, twice the bulk of hydrogen is obtained, so that this quantity, instead of weighing 1 grain, must weigh 2 grains. The proportion by weight is therefore 16 grains of oxygen to 2 of hydrogen; or 8 to 1, as was expressed above. Chemists are thus led to the conclusion that water consists of a combination of hydrogen and oxygen in the definite proportions of 2 volumes of hydrogen to 1 volume of oxygen, or of 2 parts by weight of hydrogen to 16 parts by weight of oxygen.

When a compound is resolved into its components the process is called **analysis.**[1] All the processes hitherto described have been analytical processes, but the composition of water can also be demonstrated by **synthesis,**[2] that is to say, by putting the constituents together under conditions in which they will combine to build up the compound. This happens when hydrogen is burnt in oxygen or air. Indeed, as most fuels contain hydrogen, water vapour is one of the products of their combustion; as may be shown by holding a cold body, such as a piece of polished metal, above a flame, when the vapour may condense as a film of moisture upon it. The discovery of the composition of water was indeed made originally by synthetical, and not by analytical, processes.

Impurities in natural waters.—Though absolutely pure water consists of two gases, oxygen and hydrogen, united in definite proportions, such is not the composition of any water known upon the surface of the earth. As a matter of fact, absolutely pure water is never found in the economy of Nature. Rivers are often appreciably turbid, the muddiness being due to the presence of solid particles which are mechanically suspended in the water—particles which would in great measure subside if the water were left free from disturbing causes, and which could be more or less completely removed by the simple process of filtration. Apart, however, from these mechanically suspended impurities, the water of every river contains certain chemical compounds in a state of solution. Such impurities, though present in very large proportions, may entirely elude observation by the eye, the water remaining clear and colourless. These soluble constituents, unlike the suspended impurities, will not be deposited when the solution is allowed to stand, nor will they be removed by the mere act of filtration.

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[1] *Analysis*, from ἀνά, *ana*, again; λύσις, *lusis*, a separation.

[2] *Synthesis*, from σύν, *sun*, together; θέσις, *thesis*, putting.

It is not necessary to go far to seek the source of these dissolved impurities. All the rocks of the earth, over which the waters flow, or through which they drain, contain mineral constituents more or less soluble in water. Water is, in fact, an almost universal solvent, whether of solids, liquids, or gases. River-water must therefore be regarded, not as absolutely pure water, but rather as an extremely weak solution of certain chemical compounds. What these compounds are will now be explained.

Atmospheric gases in rain water.—When natural water is evaporated, all its impurities, except those which are volatile, are left behind, and the vapour which rises is very nearly pure water. When the vapour of water is condensed it reproduces pure water. But such water rapidly absorbs both oxygen, nitrogen, carbon dioxide, and ammonia: and hence the rain when it reaches the earth is no longer pure water; it has absorbed some of the atmospheric gases. Rain-water, therefore, although the purest of all forms of natural water, contains certain impurities which it has washed out of the atmosphere. The oxygen of the air is more soluble than the nitrogen; the carbon dioxide gas is much more soluble than either oxygen or nitrogen; and the ammonia is far more soluble than any of the other gases. Thus, at a temperature of 0° C. and pressure equal to a barometric height of 30 inches, 100 volumes of water will dissolve 2 volumes of nitrogen, 4 volumes of oxygen, 180 of carbon dioxide, and 114,800 of ammonia. All the constituents of the atmosphere will therefore be found in a state of solution in rain-water; while other bodies, such as nitric acid, also derived from the atmosphere, are not unfrequently present. In fact, whatever soluble constituents exist in the air will be absorbed by the rain. Hence, in the neighbourhood of towns, where the atmosphere is impure, the rain-water will wash out more or less of its impurities, and, consequently, the rain collected in populous districts is less pure than that collected in an open country. Moreover, the rain which falls at the beginning of a shower is more contaminated than the later rain; and rain which falls after a long drought is more impure than that which falls towards the close of a rainy season. But even after a long continuance of wet weather the rain will still contain atmospheric gases to the extent of about seven cubic inches to a gallon.

Solvent action of springs and streams.—When the rain reaches the surface of the earth, it immediately commences to attack the rocks on which it happens to fall. Whether it dissolves much or little will depend upon whether the earth contains more or less soluble matter. But, whatever the character of the ground, something will certainly be always dissolved. Every runnel, every brook, every rivulet, thus washes out some of the soluble constituents of the rock over which it flows, and carries them onwards to the river. The river consequently becomes the common receptacle for all the soluble matter delivered by its tributary streams. As it flows along, it grows richer in these soluble constituents, deriving them partly from the wear of its own bed and partly from that of its banks. It is not, however, by merely running over the surface of the ground that the river and its affluents derive their supply of soluble impurities, much more being probably due to the springs by which the streams are chiefly fed. Spring-water is, in fact, much richer than river-water in these soluble constituents. Nor is it difficult to see why.

To form a spring, the rain-water must sink to a greater or less depth in the ground. During its underground passage it exerts its solvent action upon the surrounding rocks. In some cases the water sinks to great depths, traversing long and tortuous passages; and in such cases it is only to be expected that, when it reappears at the surface, it will be highly charged with soluble constituents. Under pressure, at great depths, it may absorb large volumes of such gases as carbon dioxide and sulphuretted hydrogen ; or it may dissolve saline matters of various kinds, and thus acquire peculiar properties which confer upon it medicinal value.

Solvent action of carbonic acid water. — All limestones, from the softest chalk to the hardest marble, consist essentially of carbonate of lime ; and as this compound is slightly soluble in water, the springs and streams of limestone districts always hold it in solution. It is true that the proportion of carbonate of lime dissolved by *pure* water is extremely small ; not more, it is said, than two grains in a gallon of water. But, when water is charged with carbon dioxide, the carbonate of lime is dissolved with facility ; and, since most spring-water contains this gas, it is easy to understand how it can act with great effect upon limestone rocks. It has been seen that carbon dioxide is dissolved out of the atmosphere by rain-water ; and, in like manner, every piece of water exposed to the air must absorb it, and a large

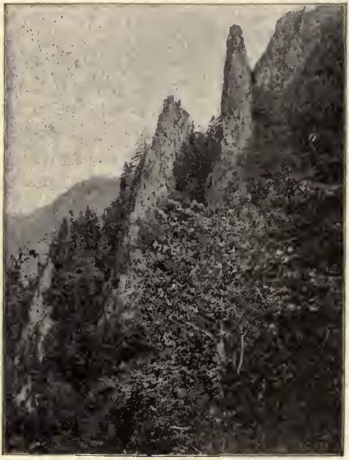

FIG. 79.—In the Bode-thal, Harz Mountains. Effect due to the erosion of silicates by water charged with carbonic acid from the soil, and assisted by frost. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

quantity is obtained from decomposing organic matter in the soil. Hence, all natural waters can dissolve carbonate of lime with more or less ease, and thus erode the limestone rocks through which they drain.

Chemical action of rain-water.—The small quantity of carbon dioxide which rain dissolves from the air unites with the water to form carbonic acid. As the rain-water percolates through the soil it takes up a much larger quantity of carbonic acid from the decomposing organic matter. If this water pass afterwards through limestone, the carbonic acid attacks the carbonate of lime and forms a soluble **acid carbonate** containing a double quantity of carbonic acid. Some of the harder rocks known as "silicates" are also eroded by carbonic acid. It is this action of water and carbonic acid combined that hollows out the caves and gorges in our hard limestone (Fig. 80), and carves into fantastic shapes even such apparently insoluble rocks as granite (Fig. 79).

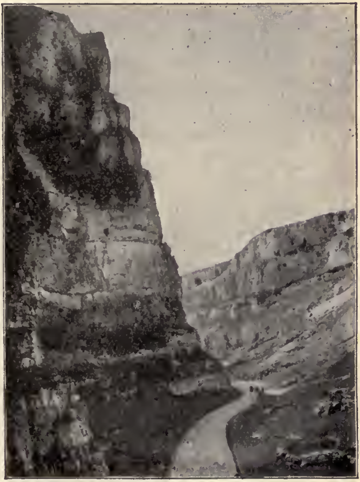

FIG. 80.—The Cheddar Gorge, Somerset. Showing erosion of mountain limestone by action of water containing carbonic acid in solution, assisted by frost. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

The softer calcareous rocks, such as oölite and chalk, are still more readily dissolved by this means; but they do not as a rule produce such rugged forms, since the angles of soft rocks tend to be worn off by the rain and frost, which have comparatively little effect on hard rocks.

Hardness of water.—When calcareous waters are used for domestic purposes, they are found to curdle soap, and are consequently termed **hard waters.** A portion of the soap is wasted, inasmuch as its fatty acids form insoluble salts with the lime.. So long therefore as this curdling continues, the soap is being wasted, and a lather cannot be produced. But it is possible to improve the condition of hard water by a process of softening, which consists in adding lime-water to the water the hardness of which is to be corrected; the lime withdraws the extra carbon dioxide from the acid carbonate of lime in the water, so that instead of one portion of soluble acid carbonate there is produced a double portion of the nearly insoluble ordinary carbonate. This falls as a precipitate, and leaves the water softer.

The hardness which is thus capable of correction is termed **temporary hardness,** to distinguish it from that which cannot be removed by treatment with lime, and is consequently termed **permanent hardness.** Such permanent hardness is due to the presence of sulphate of lime. The upland waters of the West of England usually contain much more sulphate than carbonate of lime. Sulphate of lime occurs crystallised in nature, and is known to the mineralogist under the rather fanciful name of **selenite,**[1] whence waters containing much sulphate of lime are termed **selenitic waters.** If a water be described simply as **calcareous,** it is generally assumed that the particular salt of lime which it holds in solution is the carbonate.

Calcareous streams and springs.—Waters flowing through limestone districts are generally charged with carbonate of lime; in many cases to so great an extent that, if the water be exposed to the air, the carbonate is spontaneously thrown down in a solid form. Springs of such water are vulgarly called **petrifying springs.** To "petrify," however, means literally to turn into stone; it should therefore be distinctly understood that all such springs are able to do is simply to cover the objects which receive the water with a crust of carbonate of lime, and not actually to convert them into mineral matter. Thus, at Matlock, in Derbyshire, and Knaresborough, Yorkshire, the water flowing through the Carboniferous Limestone is caused to deposit

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[1] *Selenite*, from σελήνη, *selene*, the moon

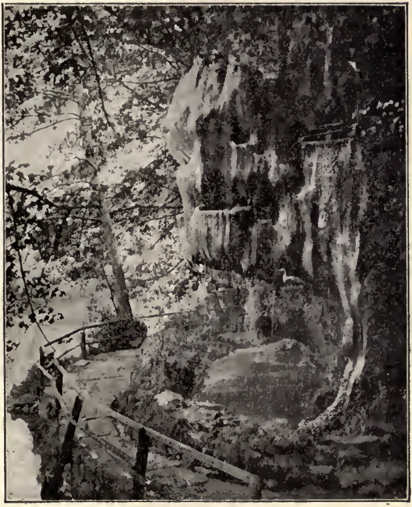

FIG. 81.—The "Dropping Well" of Knaresborough, Yorks. When the water from the well evaporates, a thin crust of carbonate of lime is deposited upon objects exposed to its action.

its carbonate of lime upon various objects exposed to its action, and in this way the so-called petrified birds' nests and other curiosities are produced (Fig. 81). Thick deposits of carbonate of lime are frequently formed by calcareous springs where they issue into the air.

Stalactites and stalagmites.—In consequence of the comparative ease with which limestone yields to the solvent action of carbonic acid solution, this rock is frequently worn by water into holes and caverns. When calcareous water finds its way through the roof of a cavern it slowly deposits its burden of carbonate of lime, or at least a portion of it, in a solid form; and, by long continuance of this action, ultimately produces a conical or cylindrical body hanging like an icicle from the rocky roof. Pendent rods of this kind are termed **stalactites.**[1] From the point of the stalactite, water slowly drops down upon the floor, and, as this water likewise contains carbonate of lime, another calcareous deposit is formed as a little conical mass

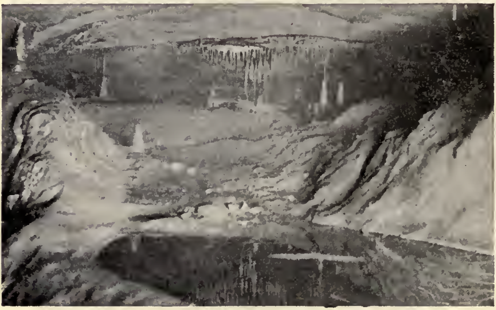

FIG. 82.—Stalactites and stalagmites in Clapham Cave, Yorkshire. From a photograph by Mr. G. Fowler.

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[1] *Stalactite*, from σταλάσσω, *stalasso*, to drop.

seated on the floor; this mass is termed for distinction's sake, a **stalagmite.**[1] As the stalagmite grows in height, it approaches the stalactite above, which continues to grow downwards; and ultimately the two may meet and thus form a solid pillar stretching from floor to roof. Fig. 82 will give some idea of the common shapes assumed by stalactites and stalagmites. In the formation and decoration of such caves, water is the main agent from beginning to end. Finding its way through the cracks and crannies of the solid rock, it first eats away the limestone so as to form the cavity, and then bedecks the roof, the floor, and the walls, with calcareous deposits of most fantastic shapes. Even without going into a limestone cavern, examples of these stalactites may readily be seen. In fact, it is by no means uncommon to see small stalactites hanging down, like icicles, from the roof of the arches of a railway bridge, where they are produced by the rain-water dissolving the calcareous matter contained in the roadway, or in the materials of which the arch is composed.

Mineral springs.—Calcareous salts, although the most common, are by no means the only mineral compounds which occur in natural waters. Some springs, such as those at Epsom, are rich in sulphate of magnesium; whence this salt is popularly called *Epsom salts*, while the springs themselves are said to be **saline.** Others may contain salts of iron, and form **chalybeate** springs.

It is notable that many mineral springs have a temperature higher than that of the locality in which they issue; thus the warm springs of Bath have a temperature of nearly 120° F. In volcanic districts, such thermal sources are extremely common, and as water when hot dissolves most substances more freely than when cold, these springs are often rich in mineral matter. The famous **geysers** of Iceland and of Colorado are intermittent boiling springs, containing in solution a good deal of silica, or the matter of which flint and rock crystal are composed.

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[1] *Stalagmite*, from στάλαγμα, *stalagma*, a drop.

Saline constituents in river water.—Springs such as have been referred to above are of course exceptional; but it should be remembered that all spring water contains more or less mineral matter in solution. On comparing the composition of river water with that of spring water, it will generally be found that the river contains less saline matter. In fact, the water discharged into the river by springs becomes diluted by direct influx of rain, and this dilution more than compensates for loss by evaporation; so that, on the whole, the proportion of salts diminishes. Moreover, the organisms inhabiting the river derive their needful supply of mineral matter, directly or indirectly, from the surrounding medium, and thus the fresh-water shell-fish and crustaceans appropriate a large quantity of carbonate of lime to form their shells, from the river in which they live. Much of this, however, must be returned to the river by the decay of the shells after the death of the animals. In these and other ways it is easy to account for the proportion of saline constituents being less in river than in spring water. If the river drain a country composed of hard and almost insoluble rocks, the water will contain but

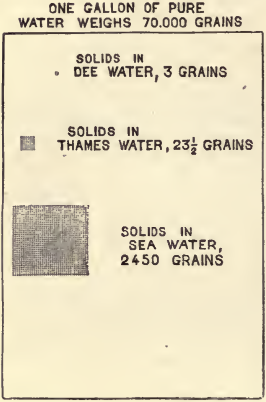
ONE GALLON OF PURE WATER WEIGHS 70.000 GRAINS
SOLIDS IN DEE WATER, 3 GRAINS
SOLIDS IN THAMES WATER, 23½ GRAINS
SOLIDS IN SEA WATER, 2450 GRAINS

FIG. 83.—Graphic representation of the salts dissolved in river and sea water. The area of the white oblong figure represents the weight of one gallon of pure water.

little mineral impurity. Thus the water of the Dee, of Aberdeen, which draws its supply from a granite district, contains only about three grains of saline matter in the gallon. It is a very different case, however, with a river like the Thames, which collects its water from the drainage of comparatively soft and soluble rocks; the result being that at London Bridge a gallon of water, that is, 70,000 grains, contains about 23 grains of saline matter. (Fig. 83.)

Dissolved matter transported by a river.—Although this proportion of mineral matter held in solution in Thames water may appear extremely small, it must yet be remembered that, taking into consideration the great volume of the Thames, the total quantity of matter removed in this way from the land and carried seaward is something enormous. Taking the daily discharge of the Thames at Kingston at 1,250 million gallons, and the salts in solution at 19 grains per gallon, the quantity of mineral matter carried down in solution, at that locality, amounts to 3,364,286 pounds, or 1,502 tons, every twenty-four hours; or say, roughly, a ton a minute. Of this amount about 1,000 tons will consist of carbonate of lime and 238 tons of sulphate of lime. The total quantity of saline matter carried invisibly away by the Thames from its basin above Kingston will thus reach, in the course of a year, to the enormous amount of 548,230 tons.

Organic impurities in river water.—Although it has been shown that river water contains a smaller proportion of saline matter than is present in spring water, it would yet be a great mistake to assume on this ground that the river water is more pure and wholesome. On the contrary the river water, though poor in mineral matter, is usually rich in organic impurities, and much less fitted for drinking purposes. Most of the water from deep wells and springs contains the merest trace of organic matter; but a river derives a large proportion of organic impurity from the decomposing vegetable matter, spread over the large surface of country which it drains. A more serious source of contamination, however, is to be found in the sewage which is allowed to run into it from the centres of population seated on or near its banks, and may be charged with matters capable of propagating disease. In a shallow stream, which flows rapidly over an irregular bed, and is thus thoroughly aërated, the organic impurities derived from decaying animal and vegetable substances may be gradually destroyed or oxidised by the agency of living organisms. The mineral substances in solution, on the other hand, remain unaffected, save in so far as they may be consumed in supplying such matters to the organisms which inhabit the river.

Dissolved matter carried down to the sea.—The mineral salts are therefore, for the most part, borne onwards by the river and finally discharged into the sea. The sea consequently becomes the ultimate receptacle for all the saline matter washed out of the land and brought down by rivers. And yet the water of the sea differs considerably in chemical composition from that of rivers or of springs. Whilst a gallon of river water may contain in solution from three to fifty grains of saline matter, a gallon of sea water will contain something like 2,450 grains. In fact, the proportion of solid matter in sea water reaches as high as 3½ to 4 per cent., so that one hundred pounds of sea water contains nearly four pounds of mineral matter. It is well known that most of this saline matter consists of common salt, such as we use at table—a salt known to chemists as **chloride of sodium**, since it consists of two elements, namely, the gas *chlorine* and the metal *sodium*. Out of the 2,400 grains of mineral matter in a gallon of sea water, nearly 2,000 grains will consist of this common salt.

Every tide brings sea water into contact with the fresh water of tidal rivers, and the two kinds thus become mixed.

On going down a tidal river it is found that the water gradually loses its freshness as the mouth is approached. The river begins to acquire a saltish flavour, and this saltness increases until the water becomes decidedly brackish and undrinkable. Going still farther out into the estuary, the saltness becomes more pronounced; until the water is hardly to be distinguished from that of the sea itself. (Fig. 84.)

Photo. *H. W. Taunt.*

FIG. 84.—The Estuary of the Thames at the Nore.

Relative weight of river and sea water.—The fresh water brought down by a river does not, however, immediately mix with the salt water, but rather tends to float upon its surface. For, since the sea water is rich in solid matter, its density is proportionally high; that is to say, sea water must weigh considerably more than fresh water when equal bulks are compared. If a given measure of pure water weighs 1,000 lbs., the same measure of water from the sea will weigh about 1,027 lbs. As a consequence of this high density, it is easier to swim on salt than on fresh water. Hence, too, the fresh water carried down by a river tends to float for a time upon the surface of the dense sea water; and off the mouths of some great rivers the water is found to be nearly fresh for some distance out to sea.

Erosion of land by water.—From the vast surface exposed by the sea, water is continually being evaporated by the aid of solar heat. But it is practically pure water which is thus drawn up into the atmosphere, the saline constituents of the sea water being left behind. Pure water condenses from this vapour, and falling upon the land as rain, charged to a certain extent with the constituents of the atmosphere, it washes out more or less of the soluble constituents of the rocks, which are ultimately carried down to the sea, where they accumulate. There is, consequently, a never-ceasing transference of solid matter from the land to the ocean—a transference, however, which entirely escapes cognisance by the sight, since the matter is carried down in a state of invisible solution. But in addition to the dissolved mineral matter which thus eludes observation, rivers bear a vast quantity of other solid matter in a state of mechanical suspension, and therefore readily recognised by the eye. This mechanical transport of solid matter from earth to sea will form the subject of the next chapter.

CHAPTER VIII

THE WORK OF RAIN AND RIVERS

Sediment of rivers.—Take a gallon or two of water out of a river near its mouth, or when the water is turbid, as after heavy rain, and allow it to stand quietly in a clean vessel. If you look at it after it has stood for several hours, you will find that the water is much clearer, and that a quantity of muddy matter is spread over the bottom of the vessel, the quantity being greater or less according to the condition of the river at the time you happen to examine it. This mud was previously held in suspension by the water, and was the main cause of its turbidity; so that, as soon as the muddy particles settled, the water became clearer. While the water was in the river, the fine solid particles were kept in constant agitation by the current of the stream, and were thus prevented from settling down. The more rapid the stream, the greater is its power of carrying this suspended matter; but, as the river approaches its mouth, the flow becomes slackened and the sediment subsides. Hence, in the lower part of the course of many rivers, especially in the "reaches" or bends of the river, there are large mud banks; and this mud is systematically dredged up and removed in order to prevent obstruction. Those particles of mud which are very light may be kept suspended in the water until they are carried by the river right out to sea; but a time at length comes when even these will quietly settle down upon the sea-bottom. If a little of the muddy sediment deposited by the water be dried by exposure to the air, it will be found to harden into a substance not unlike **clay.** Clay is in fact generally formed of mud, hardened and perhaps otherwise altered.

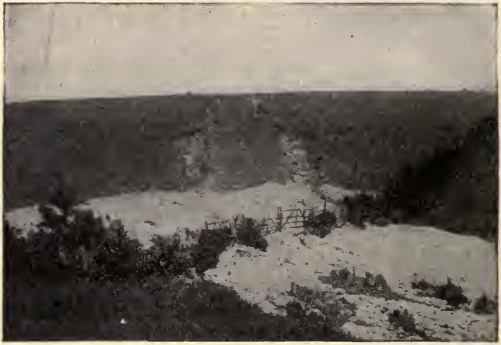

Photo. *Bielby and Son.*

FIG. 85.—During a thunderstorm and cloudburst at Langtoft, East Yorkshire, on July 3, 1892, the force of the water scooped out three deep and wide trenches from the hillside, and carried the material to lower levels.

Waste of the land by rain.—Very little thought is necessary to convince any one that the fine particles of solid matter which form mud are produced by the mechanical waste of the land. After a heavy shower of rain has fallen in the street, you observe dirty streams coursing along the gutters, and every one knows that the muddy matter in these streams is merely the dirt washed from the roofs of the houses and the stones of the street. In like manner, every shower of rain that falls in the open country washes something off the surface of the land. This removal of matter is termed **denudation** [1] since the rocks are laid bare by having their superficial covering thus peeled off. The particular kind of denudation effected by means of rain is called **pluvial** [2] denudation. A heavy shower falling upon a field washes away some of the soil, and carries it off in muddy runnels to the nearest stream, whence it passes to the river.

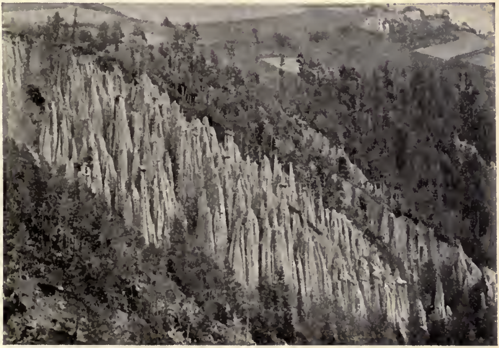

FIG. 86.—Botzen in Tyrol; showing the formation of earth-pillars by the action of rain. Reproduced, by kind permission, from a photograph by Mr. R. Kidston, F.R.S.

Where the rain comes down in a deluge, as often happens in the tropics, its power as a denuding agent is almost incredible; and even in our own country, especially among the hills of Wales and Cumberland, we occasionally hear of torrents of rain tearing up rocks and sweeping everything before them.

A striking example of the waste of land by rain is afforded by the **earth-pillars** to be seen at Botzen, Tyrol (Fig. 86).

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[1] Lat. *dēnūdo*, to lay bare, uncover.

[2] *Pluvial*, from the Lat. *pluvia*, rain.

A valley which was once partially filled with clay containing boulders has there been acted upon by rain, which has washed away the clay except where a boulder has protected it like a cap or umbrella. Each pillar has a boulder at its summit, and when this falls off the pillar is worn down by rain until another boulder is reached which will protect it from further destruction. Earth-pillars of this kind are thus due to the mechanical action of rain, and not to the solvent powers of rain-water already described (p. 128).

Formation of gravel and sand.—The detrital matter which is worn away from the land and carried along by rivers contains materials of every degree of coarseness. It often happens that fragments of rock, perhaps of considerable size, are loosened from cliffs near a river by the action of rain and frost, and tumble down into the stream. There they get slowly worn down by constantly knocking against each other, and may ultimately be rubbed into the form of smooth round pebbles. In the basin of a river like the Thames it is common for the hard flints from the chalk to get broken and rolled about in the water, and it is in this way that **gravel** is formed. The substance which is strewn over roads and garden-walks in chalky or flinty districts consists chiefly of little bits of flint, which have been so rolled about in water that the sharp points of the broken stones are rounded off. All gravel has not, however, been subject to the same amount of rough usage, so that whilst the pebbles are in some cases well rounded, in other cases they retain more or less of their angularity, though the corners are never quite sharp. The small pieces worn off the fragments of rock, as they rattle together on the bed of the stream, get rolled about until they form small rounded grains known as **sand.** As a rule, both the gravel and the sand consist chiefly of the substance called **silica,** or the material of which flint is formed, of which rock crystal (p. 63) is a very pure variety. The gravel and the coarser sediment are pushed along the bottom of the river by the motion of the stream, whilst the finer sand may be carried in suspension, though it will not travel so far as the lighter particles of mud. The heavier pieces naturally fall to the bottom first, so that if a quantity of mixed gravel, sand, and mud be shaken up in water, it will be found that the gravel is the first to fall; then the sand subsides, and finally the mud settles down.

Carrying power of running water.—If a river has a steep bed it generally possesses great carrying power Mountain-torrents, for example, rush down steep slopes and not only transport vast quantities of gravel, sand, and mud, but often move stones of considerable weight. During floods, too, ordinary rivers acquire great mechanical power. Thus we read of floods sweeping away bridges, tearing up rocks from the banks of the river, and carrying along stones weighing several tons.

In estimating the carrying-power of running water, it must be borne in mind that the weight of a stone is considerably less in water than in the atmosphere. When a body is immersed in water, it is buoyed up with a force equal to the weight of a quantity of water having the same size, so that it appears to lose a certain proportion of its weight, the proportion depending upon its specific gravity. If a stone be twice as heavy as an equal bulk of water, it will lose one-half its weight; if three times as heavy, it is lightened by one-third; and so on. Experiments have shown that if a stream flow at the rate of six inches per second it has power enough to carry off fine sand; if at 12 inches per second it can sweep away fine gravel; and if at 36 inches per second it can transport pebbles as large as hens' eggs. From these results it will be seen that by increasing the velocity six times—from 6 to 36 inches—a current is able to carry pebbles more than three inches in diameter instead of fine silt. In fact, when the velocity of a stream increases, the transporting power increases in a far greater proportion. Thus, by doubling the velocity, the transporting power is increased 64 times, and by trebling it the transporting power becomes 729 times greater. It should not be forgotten, however, that the shape of the fragments greatly affects the ease with which they may be moved in water.

Denudation by rivers.—Hitherto, the work of the river has been regarded as chiefly that of transporting solid matter which has been carried into it by rain and other denuding agents. But the river is itself a powerful agent of direct denudation—**fluviatile** denudation as it is sometimes termed. It is true that running water alone can do but little towards abrading a hard rock; but the pebbles, sand, and other detrital matter carried along by the stream rub against every hard point with which they come in contact, and thus enable the river to wear away the hardest rocks in its course, as surely as though they were being ground and scoured with sand-paper. The grinding action of pebbles, when set in motion by water, is strikingly shown in the formation of **pot-holes** (Fig. 87). These are roundish cavities, perhaps several feet in depth, not uncommon in the hard bed of a mountain-stream. A few pebbles, lodging in a small cavity, get whirled round and round by the eddies of the stream, until at length they excavate deep holes

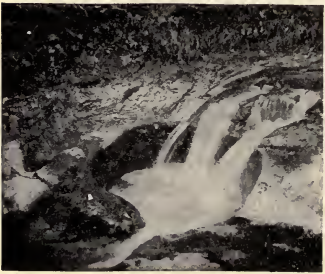
Photo. *R. Welch.*

FIG. 87.—Pot-hole in a ravine, Glenariff, Co. Antrim. The hole has been worn in basalt by the scouring action of pebbles carried by the stream.

of considerable size. In such cases, the grinding effect of the pebbles is generally assisted by the sand and finer particles in the water, which scour the walls of the hole as effectually as though they were well rubbed with fine sand-paper.

Aided by its burden of detrital matter, the river frets away the rocks along its banks and thus tends to widen its channel; while at the same time the coarse sediment, scratching along the bottom, helps to tear it up and thus deepen the bed of the river. Every stream with sufficient fall is in this manner continually at work, gnawing away the rocks through which it flows; so that a channel which is, to begin with, narrow and shallow may gradually become widened and deepened. The amount of excavation which can be wrought in a given time by means of running water is well seen in volcanic regions, where rivers have cut through sheets of lava which have been poured forth at known dates (Fig. 88).

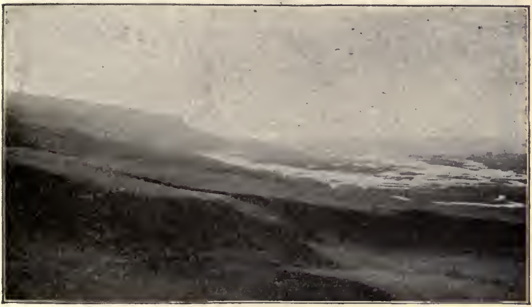

FIG. 88.—The Skaptar river flowing over lava sheet, Iceland. From a photograph by Prof. Johnston-Lavis.

The canyons of Colorado.—But perhaps the grandest results of mechanical denudation are to be witnessed in the vast chasms through which some of the rivers in Colorado flow. These narrow gorges, bounded by steep, wall-like cliffs, are known under their Spanish name of **cañons**, or with anglicised spelling **canyons** (Figs. 89, 90). The Colorado River of the West, which runs from the Rocky Mountains to the Gulf of California, flows during part of its course at the bottom of a profound chasm, being hemmed in by vertical walls which in some places are more than a mile in depth. There is no reason to doubt that this gigantic furrow has been cut down by the river which runs through it The tributary streams, flowing into the river, run in like manner through smaller ravines known as side-canyons; and in fact the general arrangement of the canyons at once suggests that of the drainage system of a country. Nothing can show the amount of *vertical* erosion effected by running

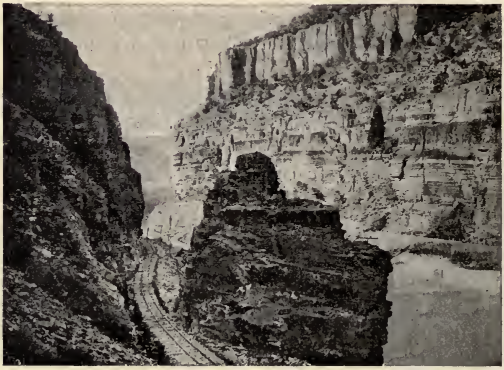

Photo. *Photochrome Co.*

Fig. 89.—The Portals, Grand River Canyon, Colorado.

water, better than these gorges. Probably they owe the preservation of their peculiar form to the fact that the country in which they occur is comparatively rainless: for, if there were much rain, the sides could not retain their position as perpendicular walls; secondary denudation would gradually wear them into slopes, and convert the chasm into an ordinary river valley.

A river system in miniature.—To understand how running water usually effects denudation, it is instructive to watch, at the seashore, the behaviour of the water which drains off a flat coast of mud or fine sand, as the tide retreats. Flat and smooth as the beach may seem to the eye, the water soon finds out some slight inequalities of surface, and runs down even the gentlest declivity. Particles of sand carried down by the water begin to scour out little grooves and then to enlarge them into wider furrows. Several streams may be seen uniting into one larger stream, and at length a complex system of branches is established, all tending to a common channel which runs down towards low water. Even without going to the seaside, one may

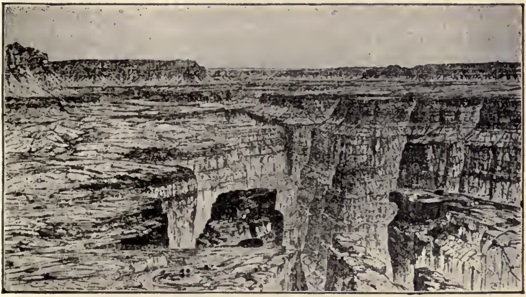

FIG. 90.—Bird's-eye view of the Grand Cañon, Colorado.

often see similar effects near a wayside puddle which receives the muddy drainage of the road. No imagination is needed to compare the miniature system of branching streams, produced in either of these cases under one's eyes, with the drainage system of a river basin. The model is in fact complete in almost every point. There is the main stream, with its side feeders, running down to the sea; and it may often be seen, that one little system of streams is separated from another by an intervening space which represents a water-parting.

Development of a drainage area.—Suppose now that a portion of the sea-bottom were to be upheaved, and appear above the surface of the water as a great area of land having a gentle slope in one direction.[1] From what has just been said, it is easy to judge at once how it would be drained. When rain fell upon this new land-area, it would tend to run down the slope towards the sea almost in direct lines, as shown at the top of Fig. 91. At this stage of development of the drainage system, all the rivers would be surface streams, their courses being determined by the slope of the uplifted plain and not by the structure of the rocks. But if the upraised area contain layers of hard as well as of softer rock, the action of rain and running water would soon wear it into irregularities. Ridges would appear which would interfere with the original direction of flow, and a new system would be developed with branching streams running almost at right angles to the courses of the original rivers. With the progress of time the plain would lose all its smoothness, and though some of the rivers might cut through the hard rock, others would be unable to do so, and a system of drainage like the bottom sketch in Fig. 91 might be produced. As this action goes on, the water-channels are worn wider and deeper, while the sides of the streams are washed by the rain into sloping banks. So close is the similarity of a system of drainage established in this way to what is found in a large river basin, that those who have thought most upon the subject believe that one may be taken to explain the other; that, in point of fact, the present rivers have gradually scooped out their own channels, and that our river valleys are mainly the result of work performed by rain, rivers, and similar agents of denudation.

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[1] *The Development of Certain English Rivers.* By Prof. W. M. Davis. *Geographical Journal*, vol. 1895.

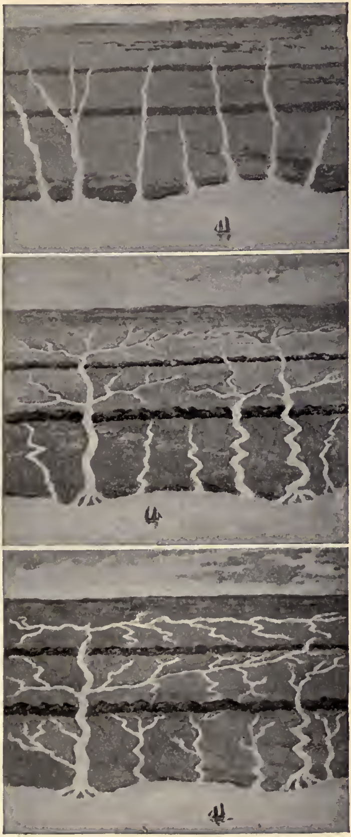

FIG. 91.—Stages in the development of a drainage system on a plateau uplifted from the sea.

River valleys.—At first sight, it may seem incredible that a great river system should have been shaped by the action of running water upon rock. Yet the more one thinks upon it the less are the difficulties that beset such an explanation. No one can deny that little watercourses may be eaten out of solid rock by a running stream, for the very origin of such gulleys may often be witnessed (Figs. 92, 93). And from these it is possible to pass, by insensible steps, to brooks and streams of larger size, until at length you come to a true river. If it be admitted that the little stream has worn out the gutter in which it runs, it is hard to deny that the larger stream has done similar work on a larger scale. The whole affair is indeed a mere question of time. The smallest cause can produce a vast effect if it is only allowed to work long enough.

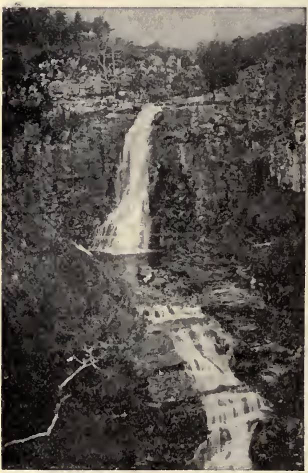

Photo. *G. W. Wilson.*

FIG. 92.—Upper Fall on the Beauly, Inverness-shire.

It needs but little boldness to apply such reasoning to the valleys of many of our rivers. If anyone will examine the opposite sides of the nearest river valley, he will probably find that the rocks exactly correspond, each bed of gravel, clay, or hard rock on one side generally having its counterpart on the other.

Passing from the study of a river valley to that of the general surface of the country, abundant evidence is to be found that rain and running water have been actively at work. Indeed, there is good reason to believe that these almost silent workers have been the chief instruments in producing the present physical features of the ground. They have eaten out river-courses and worn away valleys, leaving masses of rock which stand out as hills and crags. But, while giving them credit for effecting such work as this, it is necessary to recognise the co-operation of other forces,

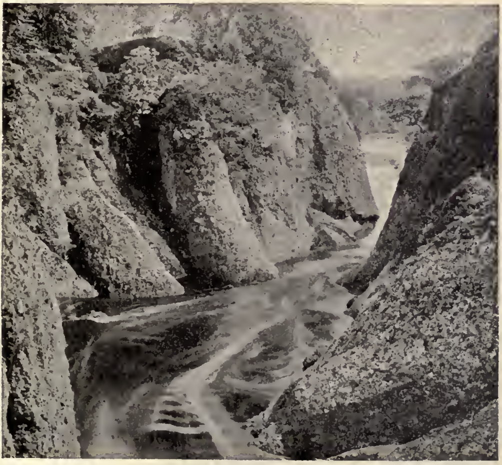

Photo. *G. W. Wilson.*

FIG. 93.—Scene on the Beauly River, Inverness-shire. Course worn by running water.

the effects of which will be discussed in subsequent chapters.

Deposition of sediment by rivers.—If running water is thus wasting away the land, year after year and age after age, what ultimately becomes of the great quantity of matter which must be removed? To this question a partial answer has already been incidentally given. The coarser detrital matter is pushed along the bottom of the stream, and thus slowly moved towards its mouth; whilst the finer detritus, being held in suspension, is carried more rapidly away by the flow of the running water. When the flow is checked, the sand and mud settle down, the coarser particles being naturally the first to subside. In the miniature river-system self-established in the muddy bank left by the receding tide, a minute stream may often be seen entering a quiet pool of sea-water, and depositing its burden of sand,

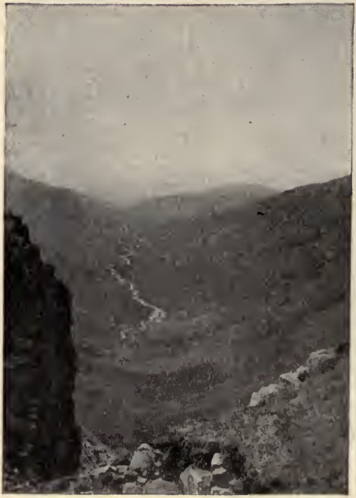

Photo. *Godfrey Bingley.*

FIG. 94.—Upper course of stream; High Cup Gill, Westmoreland, showing the character of a river valley.

particle by particle, upon the floor of the little pond. Exactly the same kind of action occurs, on a much larger scale, at the mouth of every river. In some cases a river during its course opens out into a lake, and then the resemblance to our model on the sea-shore is even more striking. On entering the lake, the flow of the stream becomes diffused over a broader area and therefore rendered slower, and a part of the suspended sediment falls to the bottom; so that, by the time the stream emerges, its waters have become purified. The effect of a sojourn in the lake is somewhat like that of allowing muddy water to stand in a glass; in either case much of the sediment slowly subsides.

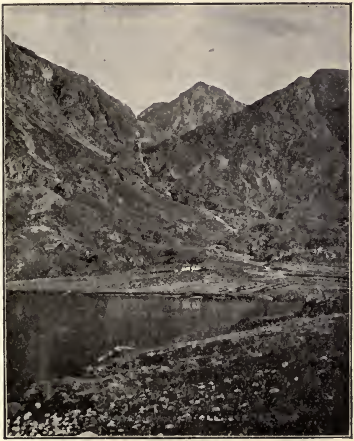

Photo. *G. W. Wilson.*

FIG. 95.—Corrie-na-baich, Glencoe, showing a delta formed where the stream enters the lake.

Silt in lakes.—A striking example of the purifying effect of a lake is seen in the Lake of Geneva, through which the Rhone flows. The river enters the upper end of the lake as a turbid stream, laden with detritus brought down from the Alps: but at the lower end of the lake it issues forth well purged of its impurities. During its passage through the lake, the mud which it held in suspension is deposited upon the bottom; and, accordingly, at the entrance of the river new land is being slowly formed by the growth of this sediment. In fact, Port Valais, the *Portus Valesiæ* of the Romans, which was originally situated on the margin of the lake, is now nearly two miles inland; the intervening ground having been formed, at the expense of the lake, by accumulated sediment delivered by the river (Fig. 96). In this way a lake may grow shallower and smaller, until at length it becomes completely silted up; and a marshy tract is formed, through which the river flows in a meandering course. Such land is generally called **alluvium**[1] (Fig. 97).

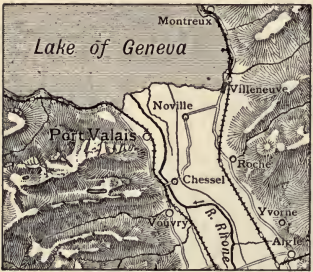

FIG. 96.—Where the Rhone enters the Lake of Geneva.

Alluvial meadows and muds.—It often happens that, without flowing into a lake, a river may get relieved of much of its burden of sedimentary matter. When an unusual supply of water is suddenly delivered into a stream, by heavy rainfall or by rapid thaw of snow, the swollen stream rises above its banks and floods the adjacent land. In a flood, or freshet, the water is always highly charged with detritus; and, on the overflow of the river, some of this is deposited as a fine layer of mud evenly spread over the flooded soil. The overflow being repeated season after season, the layers of mud accumulate until they form a low alluvial tract on each side of the stream. Most rivers are bordered by strips of rich meadow-land, which have been formed in this way. Such low-lying alluvial meadows are common along the banks of a river, and in the lower part of the basin, where the river is broad, there are often great expanses of flat marshy ground. Periodical deposition of sediment by means of river-floods is well illustrated by reference to the overflowing of the Nile. After the rainy season and the melting of the Abyssinian snows in the southern part of the basin of the river, a flood of water, charged with detritus, passes down the single channel which traverses Egypt; and, overflowing the banks of the river in its lower course, deposits the rich alluvial mud to which that country owes its fertility.

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[1] *Alluvium*, from the Lat. *ad*, and *luo*, I wash; land which is added to by the wash or flow of water.

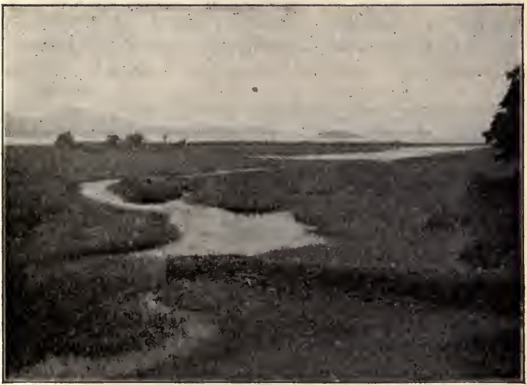


Photo. *Godfrey Bingley.*

FIG. 97.—Delta in a lake—Derwentwater—showing the character of alluvium flats.

Deltas. When a river approaches the sea, the inclination of its basin usually diminishes, its speed is slackened; and consequently it deposits more or less of the matter which it holds in suspension. If the sea near the mouth of the river is not much disturbed by currents, as in a protected bay, the sediment will accumulate, and form a tract of alluvial land which is generally fan-shaped. In Lower Egypt the Nile has in this way produced an enormous alluvial tract, which was called by the Greeks the **Delta**, in allusion to its shape resembling that of their letter Δ. About 120 miles above its mouth the Nile divides into two main streams, of which the western is known as the Rosetta branch, and the eastern as the Damietta branch, these names referring to two towns situated at their respective mouths. The two streams enclose, with the Mediterranean Sea on the north, a triangular tract of alluvial land, intersected by a network of channels. The apex of this triangle, forming what is called the *head* of the delta, is situated about ten miles below Cairo. Fig. 98 shows the form of the Nilotic delta.

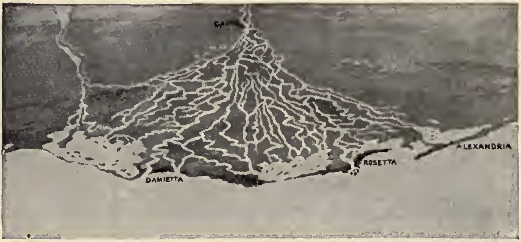


Fig. 98.—Delta of the Nile.

From being originally applied to the triangular land about the mouths of the Nile, the term "delta" has come into general use, and is now extended to all similar alluvial deposits. Even the land which has been described as formed in the Lake of Geneva by deposits from the Rhone may be called a **lacustrine delta.** If the silt is thrown down under tranquil conditions, on a tolerably level bed, it will fall in nearly horizontal layers regularly spread one upon another. Could a clean cut be made through the ground in such a delta, the cut sides would expose the edges of a number of beds or layers, of which the lowest must needs be the oldest or earliest formed, and the uppermost the youngest or latest formed; the materials of the delta are, in fact, **stratified.**

Converging and diverging streams.—In following a river from its mouth towards its source, it is sometimes found to be continually branching out into smaller and smaller streams, not unlike the ramifications of a tree, until at length it is lost in a multiplicity of little rills. And, in tracing a river downwards into its delta, it is found in like manner that it divides and subdivides, till at last it is split up into a network of channels, and reaches the sea through a number of separate openings. The arrangement of branches in the delta is therefore similar to that in the catchment-basin, but exactly opposite in direction. In the catchment-basin all the branches *converge* to the main stream; in the delta they all *diverge* from the trunk channel. The difference between the catchment-basin and the delta is shown in Fig. 99.

Nature of delta land.—In many deltas the alluvial land is swampy, or washed by the sea at high tide; and the alluvium may in some cases be traced beneath the level of the sea, in the form of shoals and sand-banks, which are made up of the lighter particles of detritus swept out beyond the true delta. The great Indian rivers, the Ganges and Bráhmapútra, form together a vast delta for the most part consisting of marshy land supporting a growth of mangroves and nipa palms. The delta of the Mississippi (Fig. 100) is an enormous tract of swampy ground in the Gulf of Mexico, furrowed by numerous streams and lakes. Holland may be regarded as an old delta, formed by the Rhine and the other rivers that pass through it. On the coast of our own country we frequently find tracts of alluvial land, such as that forming Romney Marsh. Occasionally the estuaries of our rivers become silted up more or less completely, and thus impede navigation. In the times of the Romans the Isle of Thanet was separated from the Kentish coast by a channel sufficiently wide to admit the Roman fleet; but this channel is now choked up, and the so-called island is united by an alluvial tract with the mainland.

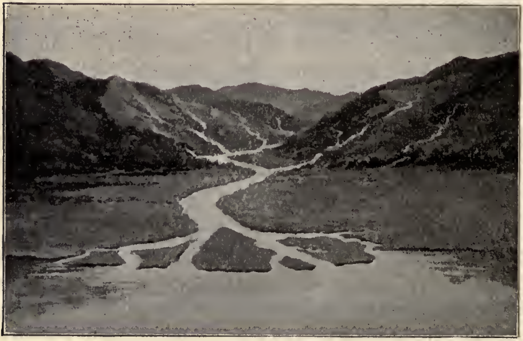


FIG. 99.—Representation of the catchment-basin and delta of a river.

River bars and shoals.—As a rule the rivers of this country are not large enough, and have comparatively too rapid a fall, to produce deltas. Moreover, in tidal rivers, the regular to-and-fro motion of the water in the estuary hinders deposition of sediment. Though the rising tide, by arresting the downward current of the river, may favour the deposition of sediment, yet on the other hand the scour of the ebb-tide co-operates with the flow of the river to sweep the sediment away. In some estuaries the tidal current is so charged with muddy matter that it is artificially carried over low land in order to cover it with a fine silt called **warp**; this is done in the estuary of the Humber. In cases where an actual delta is not formed, a **bar** or shoal may be thrown across the mouth of the river and thus interfere with navigation. A river exposed to full tidal action has little chance to form a delta; and although alluvial deposits may be found on its banks and shoals in parts of its estuary, there is sufficient scouring out of the mouth to keep the channel open.

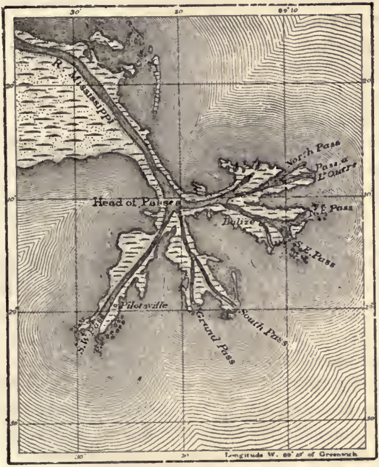


Fig. 100.—Delta of the Mississippi.

Amount of sediment carried by rivers.—But, although a river may not form a delta, the quantity of detritus which it carries down from the surface of its basin and discharges into the sea may be far from being insignificant. The proportion of solid matter suspended in water varies considerably in different rivers; and in the same river at different seasons. Thus it has been found that the water of the Rhine, when the river was turbid, contained $\frac{1}{4878}$th of its weight of solid matter in suspension; but, at another season, when the water was clear and blue, it contained only $\frac{1}{57800}$th part. The Ganges, which has formed such an enormous delta, is said to hold, on a yearly average, as much as $\frac{1}{510}$th by weight of suspended detritus. No river has been more carefully examined than the Mississippi, and it has been determined that the average proportion of sediment in this great stream is 1 to 1500 of water by weight, and about 1 to 2900 by volume; so that the weight of mud actually carried to sea in the course of a year reaches the enormous amount of more than 400 million tons. This amount of sediment would be sufficient to cover one square mile to the depth of 241 feet.

Solid matter discharged by the Thames.—With regard to the Thames, it has been estimated that it discharges annually 1,865,903 cubic feet of sediment (Geikie). Add to this the quantity of mineral matter washed away in solution, to which reference was made in the last chapter, and it will be found that the total quantity of solid matter carried to sea by the Thames is really enormous. At Kingston, as has been stated at p. 135, the dissolved matter is estimated at about 548,230 tons per year. Now, reckoning 15 cubic feet to the ton, which is about the average weight of chalk, this weight is equivalent to upwards of eight million cubic feet. But this is only at Kingston, and it is certain that much more is dissolved before the river reaches the sea. Nor must we forget to add something considerable to represent the quantity of coarse sediment pushed along the bed of the river. On the whole, then, we shall probably not be far wrong in saying that the Thames carries down to the sea every year 14 million cubic feet of solid matter.

Degradation of the land.—Imagine a huge die-shaped mass of stone measuring 100 feet in length, 100 feet in width, and 100 feet in height: this would contain one million cubic feet. No fewer than 14 of these gigantic cubes appear to be quietly stolen from the surface of the Thames basin by means of running water and transported to the sea in the course of a single year. But the Thames basin covers a very large area, and it will be found on calculation that, admitting the abstraction of this vast mass, the entire surface of the basin would be reduced in level by only $\frac{1}{800}$th part of an inch every year. At the present rate of wear and tear, therefore, denudation can have lowered the average surface of the Thames basin by hardly more than an inch since the Norman conquest; and nearly a million years must elapse before the whole basin of the Thames will be worn down to the sea-level. This method of showing the amount of work effected by rain and rivers in wearing away the land has been applied with interesting results by several geologists. Thus it has been calculated that, at the present rate of denudation, it would require about 5½ million years to reduce the British Isles to a flat plane at the level of the sea. It must be remembered, however, that such calculations are beset with grave difficulties, and that the results can only be put forth as rough approximations. Nevertheless, they are not without their value in enabling us to form a conception of the great wearing down of land which must be effected by rain and rivers.

CHAPTER IX

ICE AND ITS WORK

Destructive action of frost.—Although our attention was restricted in the last chapter to the action of rain and rivers, it would be a great mistake to suppose that these are the only agents by which denudation is effected. Rain and rivers unquestionably do much in the way of destruction, but they work with far greater effect when aided by the action of frost. Bare faces of hard rock may be exposed to the action of rain, year after year, without suffering any marked change; the water may fill the pores and fissures of the rock; yet, unless the mineral components happen to be easily decomposed, it will eat its way into the stone with extreme slowness. But when a frost comes on, the conditions are entirely changed, and a fresh element of destruction is introduced. The water with which the rock is charged freezes into ice, and during its solidification it tends to expand, as explained in a previous chapter. If the water be confined in the pores and cracks of the rock, the tendency is resisted; but the particles in freezing push each other apart in all directions, with such force that the strongest rock is sooner or later compelled to yield. Just as a water-pipe bursts during a frost, so the rock ultimately gives way. Fragments of stone, often of large size, are thus rent from the rock and ready to tumble down at the next thaw, exactly as the flakes peel off a stuccoed wall after a hard frost. Nor should it be forgotten that frost does excellent work for the farmer in breaking up hard ground. A stiff soil is more or less loosened by frost, and is thus brought easily within the reach of other denuding agents when the thaw sets in.

Expansion of water when freezing.—In addition to the mechanical force exerted by water during freezing, there are other ways in which ice assists in the destruction of the land. In a country with a mild climate, like that of Britain, the effects of ice are extremely feeble, yet they are not altogether wanting. It has been explained in Chapter IV. that when a body of water is cooled, it shrinks in bulk, like other substances; but it shrinks only when cooled down to a certain temperature. In fact, when water is reduced to a temperature of about 4° C. (39° F.) its molecules are packed more closely together than at any other temperature, so that, whether you raise or lower the temperature above or below this point, precisely the same effect is produced; the bulk of the liquid is increased. At 4° C., therefore, water is said to have its **maximum density.** This can easily be proved by experiment with Hope's apparatus, consisting of a metal or glass cylinder of the form shown in Fig. 101. Two thermometers are inserted at different levels into the cylinder of water, and the water is chilled by applying ice around the middle of the vessel. As the water becomes cooled it grows denser, and therefore sinks to the bottom,

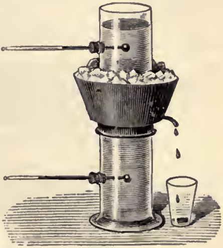
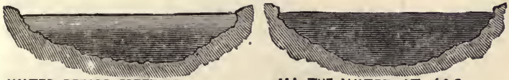


FIG. 101.—Apparatus for showing the variations of density of water near the freezing-point.

so that the temperature of the *lower* thermometer falls until it reaches 4° C. Further cooling then *expands* the water, instead of condensing it, and consequently the cold water rises, so that now the temperature shown by the *upper* thermometer, which has meanwhile been almost stationary, begins to fall, and continues falling until, like that of the lower one, it reaches 4° C. The whole body of water is then at its maximum density, and any further reduction of temperature causes expansion, the cold water becoming specifically lighter and rising to the surface. Gradually, the temperature indicated by the upper thermometer sinks to the freezing-point, but no ice can form in the inner vessel unless the ice outside is *below* the freezing-point, 0° C. It is generally necessary, therefore, to mix salt with the ice in order to obtain a lower temperature: when this is done, it will be noticed that crystals of ice begin to form at the coldest part of the inner vessel. The crystals, being lighter than water, tend to rise to the surface; though some may stick to the glass, and so be prevented from rising. At the moment of freezing, when the particles of water are trying to arrange themselves in those crystalline forms which were noticed in Chapter IV., there is an increase of bulk much greater than that described above.

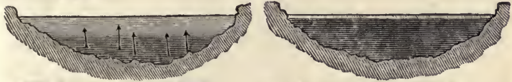
Melting ice and freezing water.—The ice outside the vessel must be below the freezing-point in order to freeze the water inside, because water at 0° C. cannot change into ice at 0° C. except by giving out a large amount of heat. But the water cannot part with this heat unless there is some colder body at hand to absorb it; for, as is well known, heat does not pass from one body to another unless the two bodies are at different temperatures. When any solid substance, such as wax, ice, or iron, is converted into a liquid, a certain quantity of heat is absorbed, and becomes hidden or latent, the amount depending upon the nature of the substance and the weight of it which is undergoing the change of state from solid to liquid. So long as the liquid state lasts, this **latent heat** is retained by the liquid, but when the solid state is assumed the latent heat is given up. Thus water at 0° C. has more latent heat than the same quantity of ice at 0° C., and when it changes into ice this heat is set free. Conversely, ice at 0° C. in the act of changing into water at 0° C. absorbs a quantity of heat from its surroundings, and this heat becomes latent in the water which is produced.

The experiment with a vessel of water near the freezing-point roughly imitates what occurs in a natural piece of water such as a lake: the surface freezes while the bottom-water remains a little warmer, at about 4° C. On account of the latent heat which water has to give up before it becomes a solid, a lake does not freeze unless the air in contact with it has a temperature below the freezing-point. When a thaw sets in, although the ice may soon rise in temperature to 0° C., it may yet take several days to absorb the large amount of heat which is necessary to convert it into water.



WATER BEFORE FREEZING HAS COMMENCED

ALL THE WATER AT 4°C



WATER BELOW A TEMPERATURE OF 4°C RISING TO THE TOP

ICE AT SURFACE. WATER AT TEMPERATURE OF 4°C

FIG. 102.—Stages in the freezing of a pond or lake.

Ground ice.—Ice, being thus relatively much lighter than water, floats upon the surface. Yet there are certain conditions under which ice may be actually formed at the bottom of a stream, and remain there for some time.

To explain the formation of such **ground-ice**, it has been suggested that the action of the running stream mechanically mixes the cold surface-water with the warmer water below until the temperature becomes uniform throughout; and when the air is very cold the whole mass may thus be reduced to the freezing-point. The formation of ice will then be determined at the bottom, in consequence of the greater tranquillity of the water and the contact of stones and other objects which have become chilled by free radiation. This ground-ice is generally found in little masses clinging to stones and weeds; and occasionally the loose bodies are lifted to the surface by the ice, just as if buoyed up with corks. The ice then floats down the river, bearing its little freight of gravel, which is dropped on the bed of the river when the ice is broken up or melted. Here, then, is a geological agent not to be neglected, since it assists the transporting power of streams in carrying solid matter from the land seawards. But if the geological importance of ice is to be fully realised, attention must be turned from these trivial illustrations to the grand spectacles which are presented by masses of moving ice in mountain regions beyond the limits of our own islands.

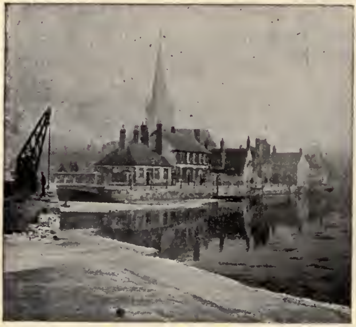


Photo. *H. W. Taunt.*

FIG. 103.—Ground ice floating on the Thames.

Snow on mountain tops.—When a snow storm occurs in this country, the snow does little or nothing in the way of denudation, beyond what it may effect indirectly, by giving rise to floods when a rapid thaw takes place. In fact the snow, as snow, protects rather than destroys. But the result is different in a mountainous country, such as that of the Swiss Alps. The greater part of the snow which falls there above the snow-line, as explained in Chapter IV., lies all the year round unmelted; and therefore every fall must needs add to the thickness of the heap piled upon the mountain top. It is true that the snow evaporates, but the evaporation is extremely slow, and is far from equal to the additions constantly received; and, though the heat of the sun during the day may melt the surface layer, the water thus formed sinks in and becomes frozen in the interior of the mass. Occasionally the accumulation is relieved by a great mass of snow sliding down the mountain slope, as an

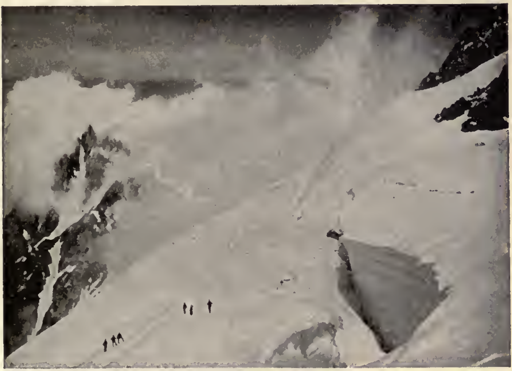


Photo. *Wehrli Bros.*

FIG. 104.—Snow-field on Mont Blanc.

avalanche. Usually, however, the pressure of the heaped-up snow gets rid of the surplus by gently squeezing it into the valleys below, where it moves down with extreme slowness. Yet it does not come down as a mass of white opaque snow. It has been shown in an earlier part of this work (p. 68) that snow is white and opaque in consequence of the air entangled among its crystals. In squeezing a handful of snow into a snowball, some of this air is forced out, and the loose crystals begin to adhere to one another; while, by compressing snow very tightly in a hydraulic press, it may be rendered almost homogeneous and thus brought nearly to the condition of ice (see p. 173).

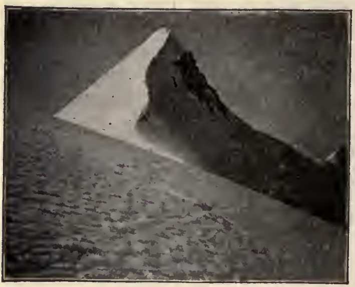


FIG. 105.—Monte Cevedale, Ortler Alps. Reproduced, by kind permission, from a photograph by Mr. O. K. Williamson.

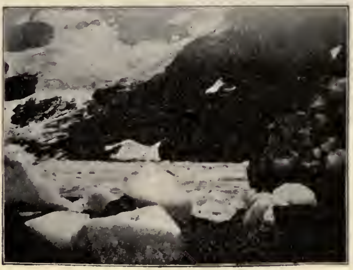


FIG. 106.—Skagastolsbrae, The Horunger, Norway. Fall of ice from snout of glacier; blocks 5 feet high hurled across a lake. Reproduced, by kind permission, from a photograph by Mr. O. K. Williamson.

Glacier ice.—In the way just described the great pressure exerted by the piles of snow in the Alpine snowfields compresses the lower layers and converts them more or less completely into ice. The imperfectly consolidated substance, partly snow and partly ice, is known in Switzerland as **Névé** or **Firn.** Moreover, the water produced by temporary thaw, or during sunshine, becomes frozen into ice; and in these and other ways the water, which fell on the mountain top as loose white snow, is ultimately sent down into the valleys in the form of solid ice. The river of ice which thus drains the high snowfields is termed a **glacier** (Fig. 107).

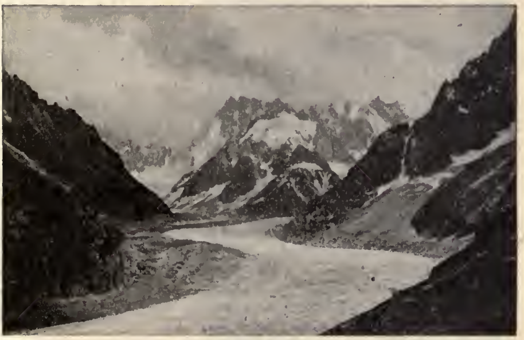


Photo. *W. M. Spooner and Co.*

FIG. 107.—Mer de Glace, from near Montanvert. A glacier winding like a river.

Movements of glaciers.—Although we have just spoken of a "river of ice," it is not easy at first to believe that a substance so solid and rigid can really move in any way like a mobile liquid. Yet the fact that the glacier does so move can easily be demonstrated. Drive a row of stakes firmly into the ice across a glacier and opposite to some well-marked point, or in a line with two stakes on the adjacent land, as in Fig. 108, so that you may know exactly their position. If you examine these stakes a week or two afterwards, you will find that they are no longer in a line with the stakes on the land, but at some point lower down the glacier. The ice has therefore moved during this time, carrying the stakes with it.

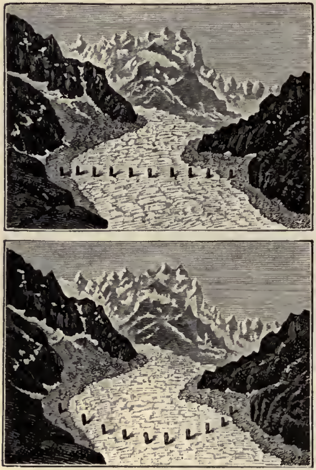


FIG. 108.—The motion of a glacier shown by the change of position of a line of stakes in the ice.

From this experiment it is seen that the ice really moves. But the experiment teaches something more than this; for it will be observed that the stakes have not only moved down, but have changed their relative positions. Instead of forming a straight line across the ice, they now form a curve; the stakes in the middle of the row have got farther down than those at the sides, and it is therefore clear that they must have moved faster.

Flow of glaciers and rivers.—The movement of the stakes in the experiment described is due simply to the movement of the ice, so that if the middle stakes move faster than the side ones, it shows that the middle of the glacier moves faster than its sides. Exactly the same thing may be observed in a river: light bodies floated on a stream move like the stakes carried down by the glacier. Nor is it difficult to see why a river should flow more rapidly in the middle than at its sides. The particles of water at the sides rub against the banks, and consequently are not so free to move as the particles in the middle of the stream.

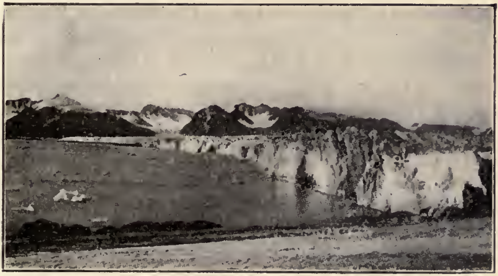


FIG. 109.—The front of King's Bay glacier, Spitsbergen. Photographed by Prof. E. J. Garwood.

In like manner, friction against the rocky walls on the flanks of a glacier causes the ice at the sides to move more sluggishly than the ice in the middle. Again, it is known that in a river the particles at the bottom drag along the bed and move less rapidly than those at the surface. The ice of a glacier behaves in precisely the same way. It is concluded, therefore, that the motion of a glacier is like the motion of a river. If the glacier enters a gorge, it becomes contracted and the flow is rapid; while, if its bed widens, it spreads out and the movement becomes slower. In truth, in all points the motion of a glacier resembles that of a river; the movement is essentially the same in kind but different in degree, the rate of movement of a glacier being much less than that of a river. The rate of movement is greater in summer than in winter, but the average pace of Alpine glaciers is about one foot per day. Arctic glaciers move much faster than those of the Alps. Thus the King's Bay glacier, Spitsbergen, is pushed downward into the sea at the rate of about twenty-five feet daily, and the Jakobshaven glacier, Greenland, has a speed of fifty feet per day.

Causes of glacier motion.—The motion of a glacier is like that of a plastic solid, such as pitch and sealing-wax. A rod of sealing-wax easily snaps if it is struck suddenly, nevertheless it will bend into a curved shape if supported at one or both ends for a few days. Here, then, we have a solid which is plastic although it is brittle, and there are good reasons for regarding ice as possessing similar properties. This sluggish motion of a glacier, and the way in which it accommodates itself to all the inequalities of the surface over which it travels, sinking into a depression, or riding over a ridge, without losing its continuity, admits of simple explanation if ice is considered to be a plastic substance. Another explanation of the motion of a glacier regards the ice as being continually fractured and refrozen; the fractures permit the ice to slip slightly down the slope, and the broken parts become joined again when they are pressed together.

Regelation.—When a schoolboy makes a snowball he squeezes a handful or two of light snow into a hard compact lump; and it is worth noting that, if the snow be just on the point of thawing, he will be able to weld it into a firmer mass than if he employed perfectly hard and dry snow. Snow, as we have seen, is nothing but a confused mass of ice-crystals; and the snowball becomes hard partly because it contains less air, and partly because the little pieces of ice of which it is composed, instead of remaining loose, stick firmly to one another. But why do they thus become welded together? Experiment shows that when two pieces of ice are pressed together they unite into one solid mass. Faraday observed this curious fact many years ago, and the phenomenon has been termed **regelation,**[1] because the surfaces are momentarily melted by the pressure, and immediately *freeze again*, cementing the pieces together. Hence it is that, when snow is strongly squeezed, the icy particles freeze together into a compact substance; and the snow, from which a glacier takes its birth, is pressed by the weight above into a hard mass, more or less like true ice.

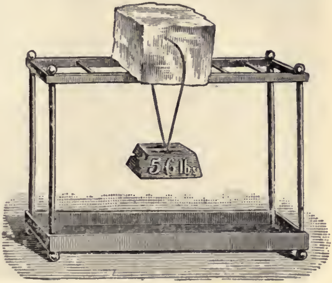


FIG. 110.—Experiment to illustrate regelation. The wire cuts through the block of ice, and the ice unites again above it.

Since water has to expand considerably in the act of changing into ice, it is not surprising to find that pressure may prevent the formation of ice, or may actually liquefy ice which is near the melting-point. A number of pieces of ice, powerfully squeezed together in a hydraulic press, are readily united into a solid lump; or a single mass may be crushed, and the fragments built up into a differently shaped body. In a similar manner, when a glacier is forced over an obstacle, the ice cracks and snaps; but the enormous pressure of the sliding mass behind squeezes it together again, and regelation heals the fractures (Fig. 110). The glacier may therefore accommodate itself to irregularities in its bed, not by virtue of plasticity, but by being successively fractured and frozen.

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[1] From Latin *re-*, again, and *gelare*, to freeze.

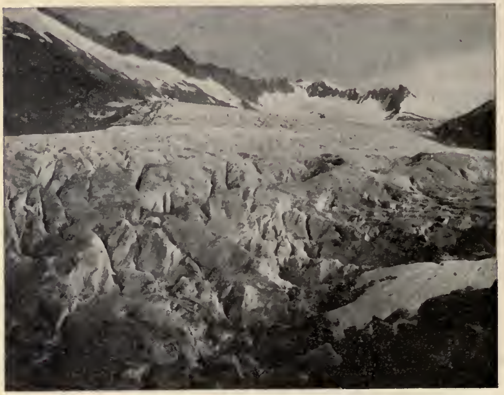

FIG. 111.—Upper part of the Rhone glacier. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

Moraines.—As it creeps down the valley, the glacier transports from higher to lower levels any detrital matter that may happen to fall upon its surface. From the neighbouring rocks fragments are constantly being loosened by atmospheric agents, and these sooner or later tumble down upon the glacier. A line of *débris* fringes each side of the glacier, some of the stones being perhaps several tons in weight. Such accumulations of detritus are known as **moraines**; and, as those which are now being described occur on the two sides of the ice-river, they are distinguished as **lateral moraines.** As the glacier moves along, the moraine matter is carried forwards, until at length it reaches the end of the glacier; and thus fragments of

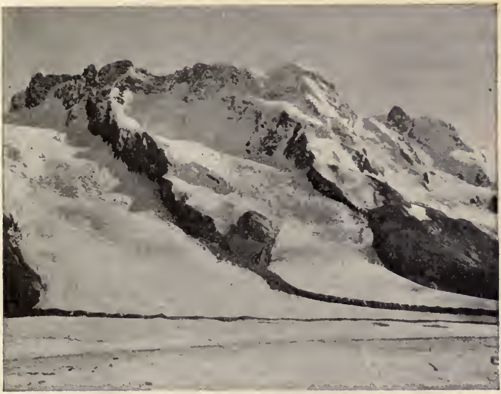

FIG. 112.—Glaciers descending from the Breithorn to join the Gorner glacier, Switzerland: lateral moraines uniting to form medial ones. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

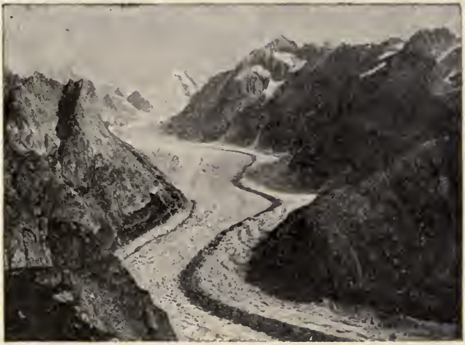

Photo. *W. M. Spooner and Co.*

FIG. 113.—Fiesch glacier and Finsteraarhorn, Switzerland. showing medial moraine.

rock may be transported down the valley, far from the heights above. The water which issues from the melting ice at the end of the glacier is unable to carry off this burden of stones which the ice has deposited; and hence we generally find, across the end of the glacier, a confused heap of rubbish known as a **terminal moraine.** When two streams of ice unite, the lateral moraines unite also, as shown in Fig. 112. It is clear that, after the union of the two branch-streams, the outer moraines will continue to occupy the sides of the trunk-glacier; while the two inner moraines will unite at the fork and form only one ridge of detritus, which will be carried along the middle of the main glacier. This middle line of stones is therefore distinguished as a **medial moraine.** If a glacier receives in its course many side-branches, each contributing its moraines, the entire surface of the ice may ultimately become strewn with rubbish.

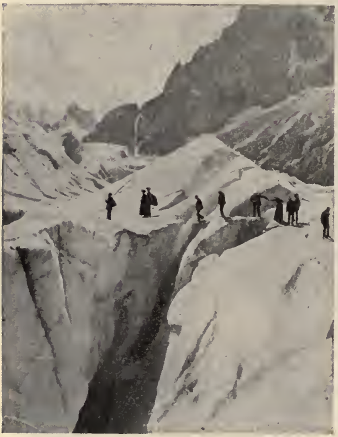

Photo. *Wehrli bros.*

FIG. 114.—Crossing a crevasse on the Mer de Glace.

Furrows formed by ice.—A glacier resembles a river, not only in its power of thus transporting detritus from a higher to a lower level, but also in acting as a direct agent of denudation. Just as a river wears away its banks and its bed, so the ice acts on the sides and bottom of the valley along which it travels. If the ice has to turn a sharp corner, or make an abrupt descent, it is forced to split; and in this way yawning chasms, perhaps hundreds of feet in depth, are produced in the glacier. Such rents are termed **crevasses** (Fig. 114). Stones, sometimes of great size, fall with a crash down these clefts, and, reaching the bottom of the glacier, get frozen into its base. As the glacier moves, these stones, pressed by the weight of ice above, scratch and score the rocky bed in the direction of the ice-flow; while the stones themselves, jammed in between the ice and its floor, get bruised in turn, so that by the time they are discharged at the terminal moraine they may be covered with groups of parallel scratches. When boulders which have fallen upon a glacier remain upon the surface for some

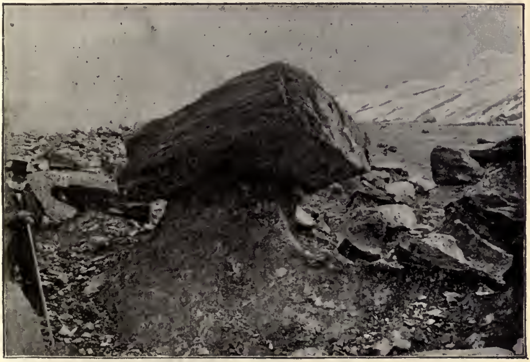

FIG. 115.—Glacier or ice tables on the Findelen glacier, Switzerland. Reproduced, by kind permission, from a photograph by Mr. C. J. Watson.

time, they protect the ice under them from thawing, by acting like a sunshade. As the surface, which is not shaded from the sun in this way, slowly thaws, the slabs of rock are left on pedestals, and form what are known as **glacier tables** or **ice tables** (Fig. 115).

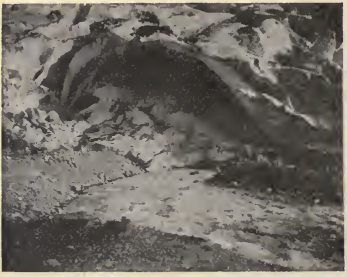

Fig. 116.—Outlet of the Upper Glacier, Grindelwald, the water issuing from a natural tunnel under the ice. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

Rock-smoothing by glaciers.—The smaller fragments worn off the rocks by the passage of a glacier, get ground down into fine gravel, sand, and mud, which may be carried in suspension by the stream of water which flows over the bed of the glacier. For it should be noted that the bottom layer of ice melts on account of the great pressure above it; and, moreover, water finds its way from the surface to the bottom through

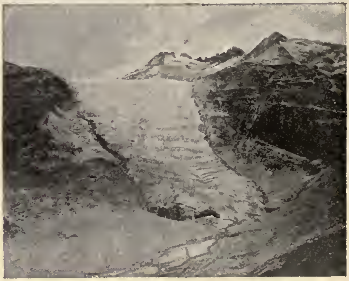

Fig. 117.—Fall of the Rhone Glacier, and source of the River Rhone, which issues from the tunnel at its foot. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

crevasses. Hence, a little liquid stream separates parts of the bottom ice from the rocky bed; and at the end, or snout, of the glacier this water issues forth, not indeed as a clear bright spring, but as a thick stream

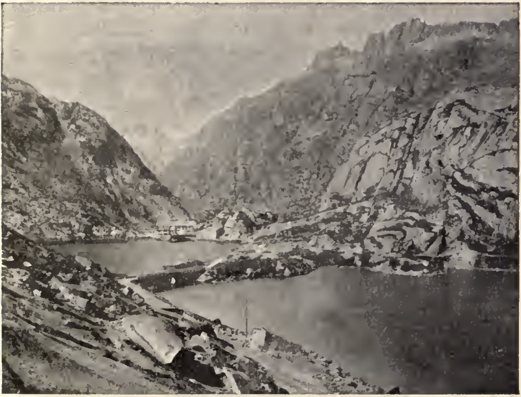

FIG. 118.—Evidence of glaciation at the Grimsel, Switzerland. The hospice in the background is at an altitude of more than 6,000 feet. The lake is scarcely ever frozen. The rocks just above the lake on the right hand are *roches moutonnées.* The serrated sky-line shows by contrast the form of rocks not glaciated, though splintered by frost.

laden with detritus (Figs. 116, 117.) The Rhine, the Rhone, the Po, the Ganges, and many other large rivers, may be traced back to muddy streams springing from glaciers. The fine detrital matter, which the water thus carries along, polishes the surface of the rock over which it flows. The action of a glacier is consequently twofold: the fine sandy matter polishes the surface, while the large stones scratch furrows. It is, in fact, as though some giant hand had rubbed the surface of the rock with fine emery powder, and at the same time rasped it with a huge file.

All rough points of rock in the path of a glacier are thus rubbed down, and projecting masses are smoothed to the form of rounded bosses. The flat-domed hummocks of rock produced in this way are termed **roches moutonnées,** and they are usually said to bear some resemblance to a flock of sheep lying down;. but this impression has arisen from a mistaken interpretation of the term, which does not mean sheep rocks[1] (Fig. 118).

Characteristics of ice action.—The passage of a glacier across a country thus gives rise to peculiar features not produced by any other agent of denudation; and, by these peculiarities we may tell with certainty that ice has been at work in a district where there is, perhaps, not a vestige of ice at the present day. In many of the valleys of Switzerland, not now occupied by glaciers, the rocks are rounded, polished, and scratched, showing that the Swiss glaciers must formerly have been of gigantic proportions and that they extended far beyond the limits retained by their present successors (Figs. 118, 119).

Ice-dammed lakes.—At an altitude of nearly eight thousand feet on the Great Aletsch Glacier, Switzerland, there is a beautiful blue-green lake called the Märjelen See. The glacier passing by the mouth acts as a barrier to the water, and a tributary valley thus becomes a lake basin (Figs. 120, 121). The "parallel roads" of Glenroy, in the West of Scotland, consisting of a series of alluvial terraces running along the sides of a valley at altitudes from about eight hundred to eleven hundred feet (Fig. 122), appear to mark the margins of a lake created in a similar way by an ice-barrier. Glaciers which formerly passed by the mouth of the valley prevented the natural escape of the water, and the parallel roads represent the beaches of the lakes thus produced at different epochs. Whenever a glacier or ice-sheet advances against or across the general slope of a country and impounds the natural drainage, glacier-lakes or extra-morainic lakes of this description are produced. Decisive evidence has been obtained by Prof. P. F. Kendall[1] of the formation of many of these lakes, of large and small dimensions, in the Vale of Pickering and other parts of the Cleveland Hills, when ice occupied the Vale of York and extended along the northern and eastern borders of the Cleveland area.

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[1] From French *roche*, rock; *moutonné*, fleecy. "De Saussure, who first applied the term, says that the rounded rocks looked like a well-dressed fleece, or one of the wigs styled in his day *moutonnées*." Prof. G. A. J. Cole.

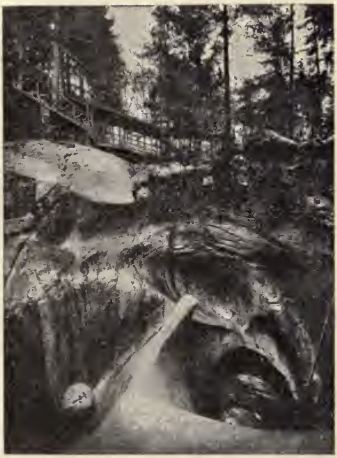

Photo. *Photochrome Co.*

FIG. 119.—"Giants' kettles," or "pot-holes," in Glacier Garden, Lucerne.

Icebergs.—On travelling northwards we find the snow-line descend, until in the Arctic regions it comes down to

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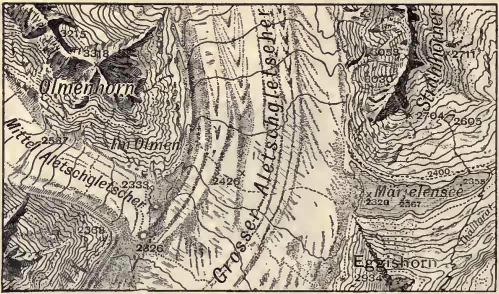
[1] *Quarterly Journal of the Geological Society*, August, 1902.



Walker & Cockerell sc.

FIG. 120.—Alpine map, showing rock peaks, glaciers, moraines, crevasses, and glacier lake. The numbers represent heights in metres. 1 metre=3·3 feet.

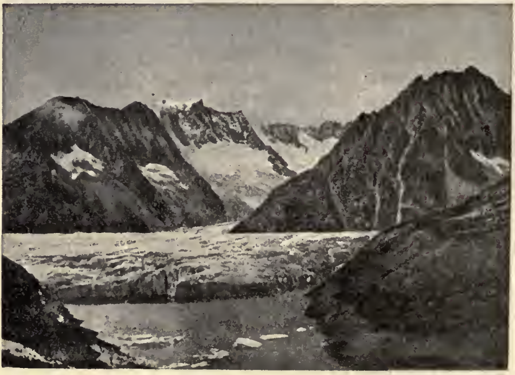


Photo. *Photochrome Co.*

FIG. 121.—The Märjelen See. A lake dammed by the Aletsch glacier.

the very sea-level. Hence in such regions the entire surface of land may be enveloped in a mantle of ice.

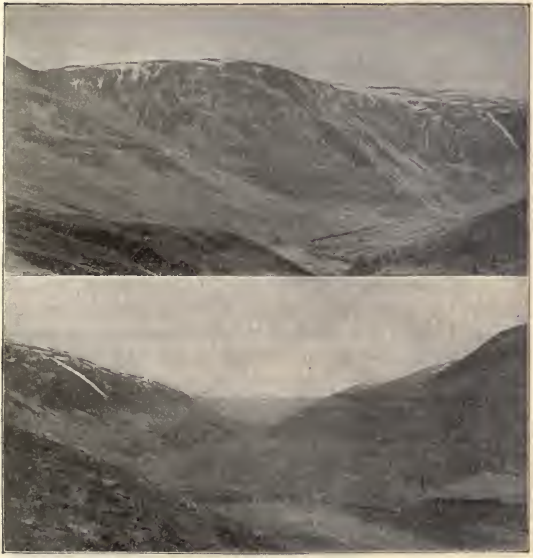


FIG. 122.—Two views of the "parallel roads" of Glenroy, Inverness The roads mark the margins of former lake levels. Reproduced, by kind permission, from photographs by Mr. W. Lamond Howie.

This ice-sheet creeps down towards the shore, until its foot at length advances into the sea. Huge masses of ice then become detached, and are sent drifting away as icebergs. These mountains of ice, like glaciers, are laden with fragments of rock worn from the land over which the ice-sheet travelled; and when on reaching warmer waters they melt, they discharge this freight of stones and earth, which may thus get carried far from their original home. When blocks of rock are borne along by running water, they become rounded by the friction to which they are subjected; but when a fragment of rock is transported on an iceberg, it may retain much of its angularity and be dropped upon the sea-bed in an almost unworn state. The finer detritus which the berg carries will be diffused through the water in which the ice melts; and currents may transport it far away into southern latitudes. If a glacier descends to the edge of a lake, exactly the same thing occurs as in the formation of an iceberg. A tongue of ice is pushed into the water, and bergs break off and float away, carrying their burden of moraine matter to be strewn over the bottom of the lake on the melting

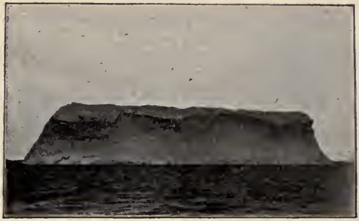


FIG. 123.—A typical iceberg of the Antarctic. From a photograph.

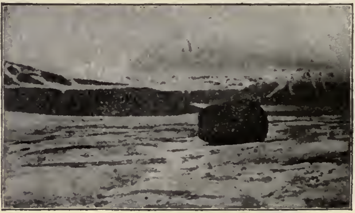


FIG. 124.—An erratic block of the Archæan moraine, Nordenskjöld glacier, Spitsbergen. Photographed by Prof. E. J. Garwood.

of the floating ice. If the bottom of the lake or of the sea should at any time be upheaved, the glacial mud and gravel, with angular blocks and ice-scratched boulders, may be exposed to view; and may thus furnish evidence of glacial denudation in countries which are now free from anything like glaciers or icebergs.

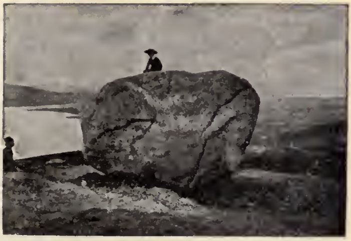


Photo. *R. Welch.*

FIG. 125.—Cloughmore, Rostrevor, co. Down. An erratic block of granite, resting on slate, at an altitude of 970 feet.

Blocks which have been carried by glaciers far from the parent rock are found scattered over a large part of the course of a vanished glacier, and are termed **erratic blocks.** Other evidence of ice-action is afforded by the peculiar position of large angular blocks of stone, poised perhaps upon the very edge of a precipice, or balanced upon a mere point. Such stones, known as **perched blocks,** could hardly have been brought into their strange position by mere rolling, or by the action of running water; but it is easy to see that they might have been dropped by an iceberg, or left stranded by the gradual melting of a glacier on which they were originally seated.

Evidence of glacial action in Britain.—Evidence of former ice-action can be seen in many parts of Britain. The traveller in Scotland, Ireland, Cumberland, or North Wales, will have no difficulty in detecting *roches moutonnées*, perched blocks, erratic blocks, and occasionally the remains of old moraines; while here and there, where the rocks have been protected, the glacial polish and striations are still preserved. Such evidence conclusively proves that ice must have flowed over the surface of the country. It is believed indeed that at one period of geological history known generally as the *Glacial Period*, Britain must have been buried beneath a

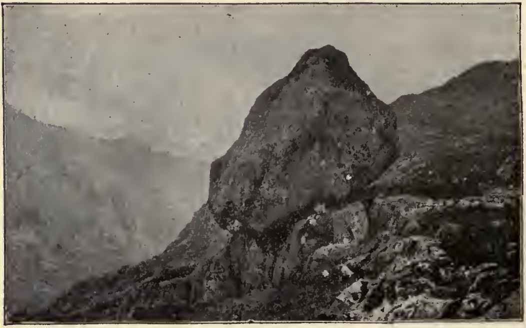


FIG. 126.—Perched block in the Pass of Llanberis. Reproduced, by kind permission, from a photograph by Mr. C. J. Watson.

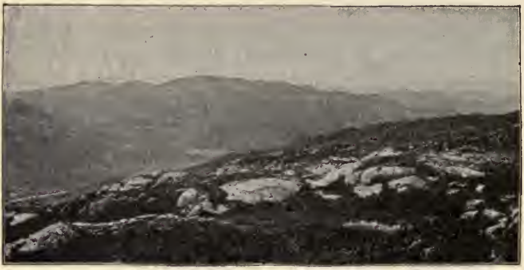


FIG. 127.—*Roches moutonnées* at Capel Curig. Reproduced, by kind permission, from a photograph by Mr. C. J. Watson.

vast sheet of ice, similar to that which now covers Greenland. This ice played its part in rasping and grinding and polishing the surface of the land, and the forms of our mountains are largely due to its action. All our mountain-lakes occupy what were formerly valleys worn by glaciers; the lower end of such a valley having become dammed up, in some cases by the accumulation of a moraine, in other cases by other means not so easy of explanation. Nor is it only the effects of land-ice which the glacialist sees marked upon the rocks of Britain. During part of the Glacial Period, the land must have been submerged beneath the waters of an icy sea; and icebergs, drifting from the north, scattered their freight upon the rocky floor which has since been upheaved as dry land. In many parts of our country, including even the neighbourhood of

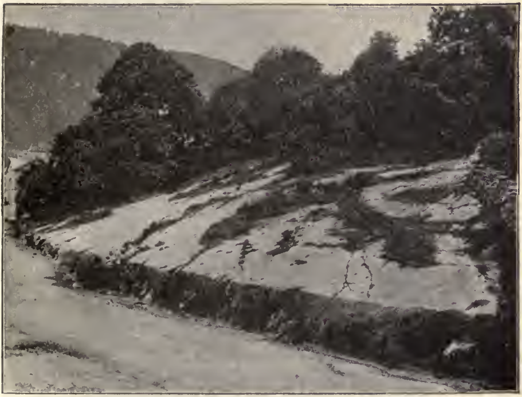


FIG. 128.—Glaciated surface at Trefriw, Carnarvon. Reproduced, by kind permission, from a photograph by Mr. C. J. Watson.

London, as at Finchley, deposits of gravel and clay may be found crowded with ice-borne boulders, which still retain their glacial scratches. This **drift**, as it is termed, not to cite other evidence, sufficiently shows that there must have been a time when ice played its part, as an agent of denudation, so far south as the basin of the Thames.

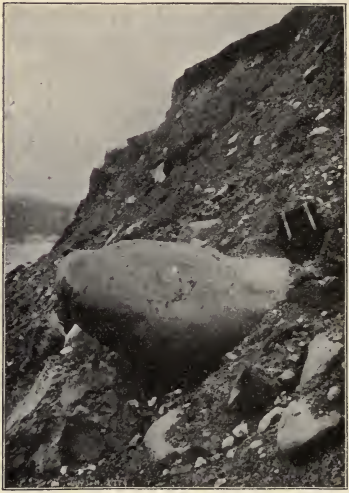


FIG. 129.—Striated boulder embedded in boulder clay, Deganwy, near Conway, North Wales. From a photograph by Mr. W. Jerome Harrison.

CHAPTER X

THE SEA AND ITS WORK

A shingle beach.—Even a blind man could not stand long upon a shingly beach without knowing that the sea was busily at work. Every wave that rolls in from the open ocean hurls the pebbles up the slope of the beach; and then, as soon as the wave has broken and the water has dispersed, these pebbles come rattling down with the currents that sweep back to sea. The chatter of the beach thus tells us plainly that, as the stones are being dragged up and down, they are constantly knocked against each other; and it is evident that, by such rough usage, all angular fragments of rock will soon have their corners rounded off, and become rubbed into the form of pebbles. As these pebbles are rolled to and fro upon the beach they get worn smaller and smaller, until at length they are reduced to the state of sand. Although this sand is at first coarse, it gradually becomes finer and finer, as surely as though it were ground in a mill; and ultimately it is carried out to sea as fine sediment, and laid down upon the ocean-floor.

The dash of the waves.—On examination of the cliffs which back many beaches, it is easy to see how these suffer by the constant dash of the waves. Rain, frost, and other atmospheric agents, playing their part in the work of destruction, attack the cliff and dislodge masses of rock, which come tumbling down to its base and accumulate there as a line of rubbish. As soon as the fragments are brought within reach of the waves, they are rolled against the cliff, bruising and battering the face of the rock, while the fragments themselves are apt to get shivered in the fray.

During violent gales the breakers acquire unusual power, and are able to move rocks of enormous weight. On the western coast of Britain, where the Atlantic breakers roll in upon the shore, they have been known to exert a pressure of between three and four tons on every square foot of surface exposed to their fury. Even in summer these waves break upon the coast with a pressure of about 600 pounds per square foot; and in winter this force is often trebled. It is easy to believe that such masses of moving water can carry with them huge blocks of stone, and hurling these against the shore, can breach it just as effectually as though it were attacked by the blows of a battering-ram. In fact, whether in storm or in calm, a cannonade more or less

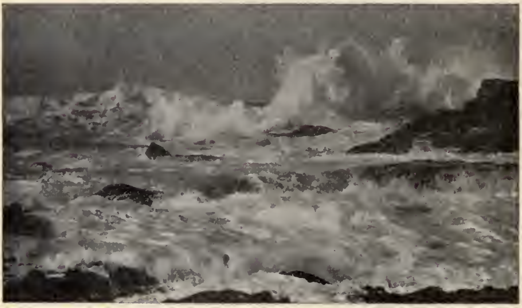


Photo. *Frith and Co.*

FIG. 130.—Breakers at Hell Bay, Scilly Isles.

sharp is constantly kept up against the coast, the ammunition being supplied by the ruins of the coast itself.

Mechanical erosion.—Were the waves to break upon the shore without the aid of any fragments of rock, the mere weight of water would naturally effect some amount of destruction; but there is reason to believe that in most cases this would be comparatively slight. It has been already shown that a river erodes its channel, not so much by its own friction, as by that of the sedimentary matter which it sweeps along in its course. In like manner, the wear and tear of the waves themselves is insignificant compared with that wrought by the boulders and pebbles, the gravel and sand, which they bring to bear upon the coast. Every wave carries, as it were, a number of stone hammers, with which it bruises and batters the cliffs; and, as this action is persistently repeated by wave after wave, the hardest rock is at length forced to yield.

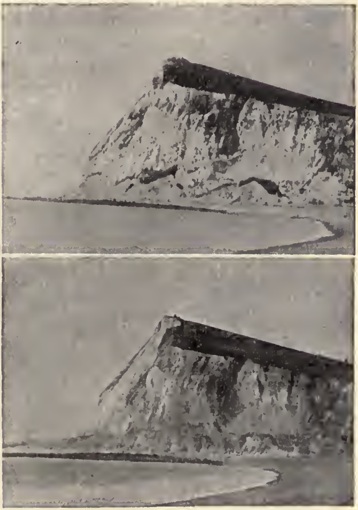


Fig. 131.—Landslip at Shakespeare Cliff, Dover, in February, 1897. The upper view was taken before the great fall, and the lower one after. Reproduced, by kind permission, from photographs by Captain S. Gordon McDakin.

Formation of caves and stacks by the sea.—Almost any part of our coast-line will serve to show the destructive effects of the sea. It is true the action is much less marked in some directions than in others; while at certain points the sea may be engaged, not in destroying, but in actually forming land, by deposition of sedimentary matter resulting from the destruction of the shore elsewhere. As a rule, however, abundant evidence of marine waste may be seen on any visit to the seaside. Bays and coves may be hollowed out in one part of the coast, and a headland may be worn away in another; here, caves are being excavated in the base of a cliff; there, tunnels are drilled through some projecting rock; while in places the cliffs are so deeply worn, that wall-like masses are left standing out as buttresses, or are even completely isolated in the form of **needles, stacks,** and **skerries.** Several examples of marine denudation at different parts of our coast are shown in Figs. 132–134. It is evident that the outstanding masses were

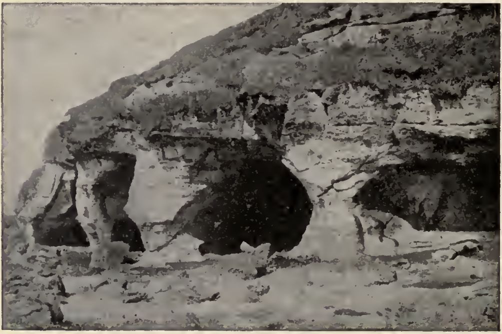


Photo. *G. W. Wilson.*

FIG. 132.—King's Cove, Arran. Sea-worn caves.

once connected with this main body, though now completely surrounded by the sea. The headlands have been beaten

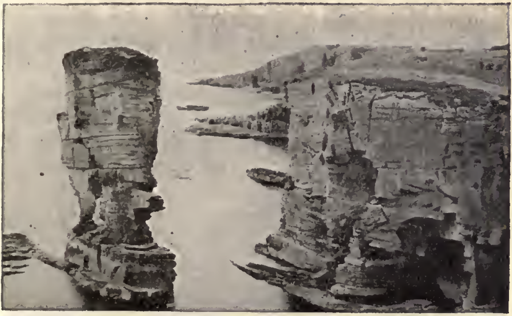


Photo. *G. W. Wilson.*

FIG. 133.—"Yesnabie Castle" Rock, West Coast of Pomona, Orkney Islands. Coast worn by the sea and weather.

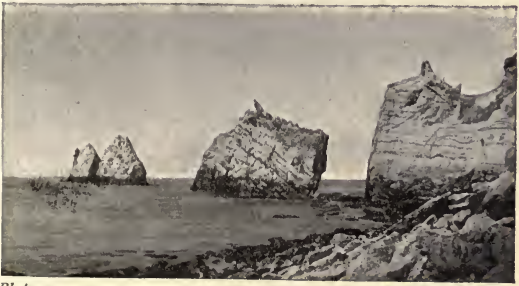


Photo. *Photochrom Co.*

FIG. 134.—The Needles, Isle of Wight. Pillars of chalk separated from the mainland by marine denudation.

about by the waves until a passage has been forced at a weak point, here and there; and pillars have thus been left standing apart from the mainland. (Figs. 133, 134.)

Characteristic cliffs.—As a general rule the hardest rocks form the most rugged outlines, because their angles are not easily worn away by the aërial denudation which rounds off the surfaces of softer rocks. But though soft rocks (for example, chalk) form no rugged cliffs inland, they behave somewhat differently on the coast; for we there find remarkably bold chalk cliffs, as at Dover, Flamborough Head, and especially Beachy Head. The cause of this difference is, that inland the base of a cliff is protected by the **talus** or accumulated detritus, while the upper part is exposed to denudation, which rounds off the rock if it be soft: whereas on the coast the sea not only washes away the detritus, but may wear the base faster than the rain and other atmospheric agents wear the summit; in this case an overhanging top is formed, from which masses of rock fall away from time to time, leaving a rugged surface. (Fig. 131.)

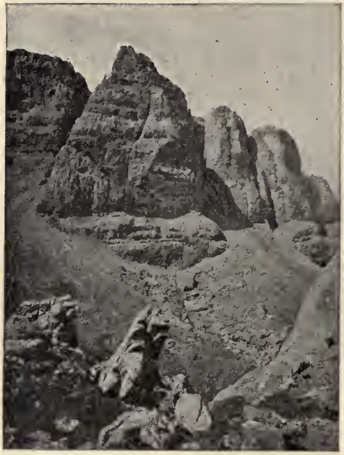


Photo. *G. W. Wilson.*

FIG. 135.—Storr Rock, Skye, showing talus due to weathering.

Nevertheless, the most rugged forms occur among the harder rocks, as may be seen on the western and northern coasts of Britain, where the rocks are much older and harder than those on the eastern and southern coasts.

Where cliffs are formed partly of hard, and partly of soft rocks, the latter will naturally be more easily attacked by the waves. The fantastic forms which sea-cliffs assume may often be explained on this principle; the harder beds, or dykes, of rock standing out in bold relief when the neighbouring softer rocks have been eaten away.

Our disappearing coast.—The land of our coasts is being worn away continually by the action of the sea. On the Yorkshire coast it is estimated that two miles have been taken by the sea since the Roman occupation;[1] and more modern records show that towns and villages have disappeared with their houses and churches, whole parishes having been washed away in some cases. Along the Norfolk coast, the only record of several villages is, "washed away by the sea"; and on the Kentish coast churches and houses have fallen down the cliffs, on which are to be seen the bones formerly deposited in a churchyard which has vanished. On

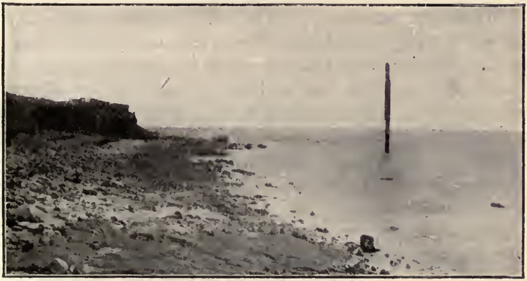


FIG. 136.—Marine denudation at Cultra, near Holywood, Co. Down. Reproduced, by kind permission, from a photograph taken by Miss M. K. Andrews, in 1891. The post in the water is part of a windmill pump erected 50 feet inland in 1824.

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[1] *Nature*, July 19, 1900 (vol. 62, p. 266).

the south coast, although the chalk cliffs at the east end of the English Channel are subject to frequent falls and slips, care has been taken to protect them; but along the clay cliffs near Axminster, South Devon, the waste is continuous, as much as twenty acres having slipped sea-ward in a single night. On the west coast, the nets of the fishermen are said to become occasionally entangled with the ruins of houses and other buildings buried in the sea some distance from the coast off Blackpool. To some extent this waste is compensated by the reclamation of land from the sea, but the area thus recovered is very small in comparison with that worn away by the unceasing operations of the sea.

Wind and wave.—If the sea were a body of water in perfect repose, it would be utterly incapable of effecting mechanical erosion. But every one knows that the sea is never absolutely at rest, and that, even in the calmest weather, its surface is ordinarily more or less troubled with waves. It is easy to understand how these are formed. When you blow upon the surface of a basin of water, the mechanical disturbance of the air is immediately imparted to the liquid, and the surface is thrown into a succession of ripples. In like manner, every disturbance of the atmosphere finds its reflex on the surface of the natural waters. Each puff of wind catches hold of the water, and heaps it up into a little hill with the face to leeward; then the crest falls, and the water sinks down into a trough, as deep below the mean surface as the hill was high above it; but the next column of water is then forced up, only however to be pulled down again, and in this way the motion of the wave may be propagated across a broad expanse of water. Drop a stone into a pond, and the same kind of action will be seen: the water all round the spot where the stone falls is first depressed in the form of a little cup, and then rises again, the motion being taken up by the neighbouring water; and a succession of circles, losing in intensity or height as they gain in width, spreads over the pond until the ripples at length die away upon the shore. If any light object, such as a cork, happens to be floating on the surface, it will serve to indicate the motion of the water below. As the waves reach it, the cork rises and falls, but it is not carried forward by the movement of the water. Exactly the same kind of action may be witnessed at sea. If a gull, for example, is seated on a wave it is simply rocked up and down, and not moved onwards.

Undulatory movement.—Such simple observations are sufficient to show that the motion of the water is a movement of undulation and not of translation; it is merely the form of the wave, and not the actual water, that travels. The motion is transmitted from particle to particle, to a great distance; but the particles themselves perform very small excursions, merely vibrating up and down, or rather revolving in vertical circular paths. The general effect is similar, as has often been pointed out, to that witnessed when a gust of wind sweeps across a field of corn. Notwithstanding the impression produced on the observer, he knows that any movement of translation is here quite out of the question; the stalks are not uprooted and carried across the field, but each stalk simply bends down before the wind and then returns to its erect position. Similarly, in the open sea the wave or pulsation is propagated, but the mass of the water at any given spot remains stationary, except in so far as it vibrates up and down.

Rollers.—The mechanical force of the wind urges the surface-water forward; and when the wind blows persistently in one direction, the disturbance which it produces causes water to well up from below to take the place of that forced onward; but this is not wave motion. The action of wind can be seen when a fresh breeze tears off the water from the crest of a wave, and scatters it as spray, and a heavy gale converts this into blinding showers of salt rain

The wind too catches the top of the wave, and causing it to move faster than the water below, urges it to leeward in the form of a graceful curl, the edge of which breaks into foam. On reaching a shore, the retardation of the deeper part of the wave by friction against the sea bottom, increases the relative velocity of the superficial part, and the latter rolls over; the water bursts with great force upon the land, and then sweeps back, as a powerful **undertow**, to the sea.

Heights of waves.—However agitated the surface of the sea may be, there is reason to believe that the disturbance never extends far downwards. The more violent the wind the greater of course will be the agitation which it is capable of producing; but even during a storm the waves never attain to anything like the height which is often popularly ascribed to them. It is not uncommon to hear of the sea running "mountains high"; yet in a strong gale in the open ocean the height of a wave, from crest to trough, rarely exceeds forty feet. In the shallow seas around our own islands they are far from attaining to such a magnitude; the largest waves, even in a storm, not exceeding eight or ten feet in height. The disturbance produced by such waves extends downwards only to a comparatively small depth. In fact, the motion of the largest waves is almost imperceptible at a depth of about 300 fathoms, or 1,800 feet; while the agitation produced by ordinary waves must be quite insignificant at one-third of this depth. So far then as the destruction of the land by the sea depends on the mechanical action of such waves, it must cease at about 100 fathoms. Indeed it is probably very feeble at depths much less than this; and in most cases on our own shores it is not very marked below the limit of the lowest tide.

Currents caused by winds.—Winds not only agitate the sea and produce irregular waves, but where they are constantly blowing over the ocean in a definite direction they cause the surface-water to take a similar course, and thus produce steady **drifts** or **currents**, the direction of which agrees very closely with that of the prevailing winds. Bottles thrown overboard from ships in the open ocean may be carried by these currents for hundreds of miles, and ultimately cast upon distant shores. Pieces of wood, and nuts and seeds, known to be native to the West Indies and tropical America, are occasionally drifted across the Atlantic, and are washed on to the western shores of England, Scotland and Ireland, and even across to Norway. In like manner the Portuguese men-of-war (*Physalia*, *Velella*) and those oceanic snails with violet shells called *Ianthinæ*, are now and then brought as visitors to our coasts, though usually confined to warmer seas far to the south and west.

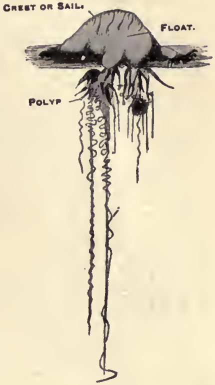

FIG. 137.—Portuguese man-of-war (*Physalia*) floating on the surface of the sea.

The Gulf Stream.—Perhaps the best known of these oceanic currents is the Gulf Stream, which is a broad body of warm water sweeping out of the Gulf of Mexico, through the Strait of Florida. The stream runs nearly parallel to the coast of the United States, and as it sweeps into the Atlantic it spreads out until a little east of Newfoundland it is not distinguishable in temperature or "set" from the rest of the ocean. (Fig. 138.)

The Gulf Stream cannot therefore be said to cross the Atlantic from the shores of North America, for it is only an incidental part of a system of circulation which causes the surface-water of the ocean to drift in a north-easterly direction. The middle portion of the relatively warm surface water reaches the western shores of Britain and even extends to the coast of Norway; while another portion parting from it in mid-ocean turns to the south and sweeps round the coasts of Spain and Northern Africa.

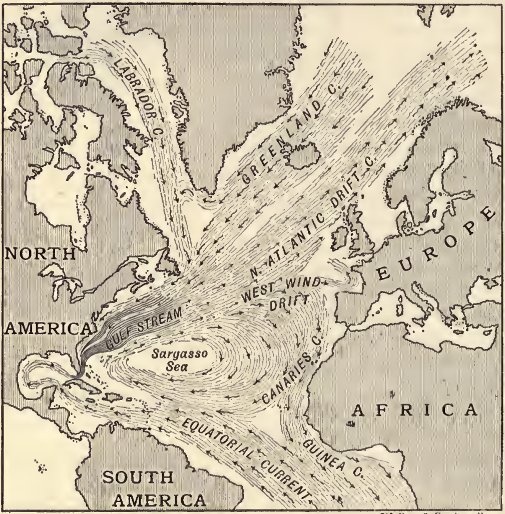

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FIG. 138.—The Gulf Stream in relation to the circulation of the North Atlantic.

Sea and air temperatures.—The Gulf Stream, and the drift of water towards the coasts of western and north-western Europe, are undoubtedly results of wind-action. There is a prevailing eastward and north-eastward drift of the atmosphere over the North Atlantic, and this causes the entire surface of the ocean north of the region of the trade winds to have a general movement towards the north-east. The aërial currents which produce this movement also distribute over Europe the heat they have derived from lower latitudes. The comparatively mild climate of north-western Europe was formerly attributed to the influence of the Gulf Stream; but since it has been proved that the stream loses itself in the Atlantic long before it reaches our shores, this view has been abandoned. Our climatic advantages must not be ascribed so much to warm water as to wind.

Observations of the temperature of the surface of the sea around the British Isles throughout the year show that at most places the sea is coldest in February and warmest in August. The lowest winter temperature is about 40° F. off the coast of Scotland, and the warmest water in winter is off the Cornwall coast—where the average temperature in February is about 47° F. The temperature of the sea around the southern half of the British Isles is about 61° F. in August, and five or six degrees less in the northern half. It is generally believed that the sea exerts a great influence upon the climate of our coasts, but by an analysis of a large number of observations Dr. H. N. Dickson has proved[1] that at no place is the average annual temperature of the sea more than two degrees greater than the average annual temperature of the air. It appears that the mild winters of our western coasts are not due to the heating of the air by contact with a surface of warm water brought by a current from warmer regions, but to the fact that the air has itself come from these warmer regions, and is charged with abundant moisture, which sets free vast quantities of heat when the vapour is condensed to form rain.

Depth of Gulf Stream.—That the Gulf Stream is an extremely shallow current of water compared with the great depth of the ocean is shown in Fig. 139, which represents a section of the North Atlantic, between New York and Bermuda. The current may indeed be regarded as a mere rill of warm water running over the surface of the sea; for, while the water below is considerably more than 2,000 fathoms in depth, the Gulf Stream itself is not more than 100 fathoms deep. It is seen also that, while the Gulf Stream has here a temperature of 75°, the bottom water has as low a temperature as 35°·3 F. Incidentally, the diagram in Fig. 139 serves to show the character of the sea-bottom along the line of section; it shows, for example, that the island of Bermuda rises as an isolated peak from water of great depth. It must, however, not be forgotten that in the diagram the vertical heights are shown on an exaggerated scale.

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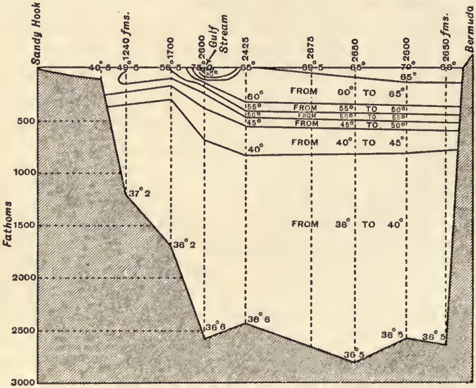
[1] "The Mean Temperature of the Surface Waters of the Sea round the British Coasts, and its Relation to the Mean Temperature of the Air," *Quarterly Journal of the Royal Meteorological Society*, October, 1889, vol. xxv.



Walker and Cockerell.

FIG. 139.—Section of the Atlantic Ocean between Sandy Hook (near New York) and Bermuda, a distance of 700 nautical miles. The figures above the dotted lines indicate depths in fathoms. Drawn to true scale this diagram would be about seventy-two feet wide.

Circulation of water.—After what has been explained in Chapter IV. respecting the effect of heat in altering the bulk of bodies, it will be understood that a body of warm water, like that of the Gulf Stream, can easily float upon water which is colder and therefore denser. When a mass of water is unequally heated, by raising its temperature below, or by lowering it above, currents are at once established; and, if light matter, such as sawdust, be suspended in the liquid, the direction of these currents becomes very evident. Thus in Fig. 140, where heat is applied at the bottom of a vessel, the liquid becomes specifically lighter and therefore rises, whilst the surrounding colder water being denser, runs down in streams to supply the place of that which has ascended to the surface. This is, in fact, the ordinary way in which heat is propagated through a body of liquid, and the process is called **convection,**[1] to distinguish it from *conduction*, or the method by which heat is propagated through solid bodies. In conduction, the heat is passed on from particle to

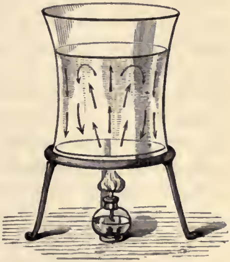


Fig. 140.—Convection currents produced in water heated from below.

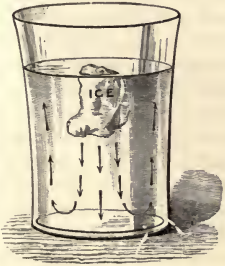


Fig. 141.—Convection currents due to ice in water.

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[1] *Convection*, from Lat. *con*, and *veho*, I carry, the heat being conveyed by currents through the fluid mass.

particle, and thus travels through the mass, while, in convection, the heated particles themselves move. Again, if a piece of ice be dropped into a tumbler of slightly warm water, a system of currents will also be established, as in Fig. 141. From the bottom of the piece of ice a clear stream of heavy cold liquid flows down the middle of the glass, like a stream of clear oil, while the neighbouring water, which is comparatively warm, flows upwards in currents nearer to the sides of the vessel.

Oceanic circulation.—Unequal cooling or heating of the great natural masses of water are competent to produce a circulation similar to that just described. The temperature of the sea at different depths has been very carefully examined; and the observations show that, as a rule, the temperature diminishes as the thermometer goes deeper, just as was shown to be the case in the North Atlantic. Reference to Fig. 139 shows that the bottom-water of that part of the ocean has a temperature only a little above 36° F.; while, in other places, it is still lower, and may even descend below the freezing-point of fresh-water.[1] It appears that the presence of such cold water in the deeper parts of the ocean, even in tropical regions, can hardly be explained otherwise than by assuming a grand movement of water from the polar towards the

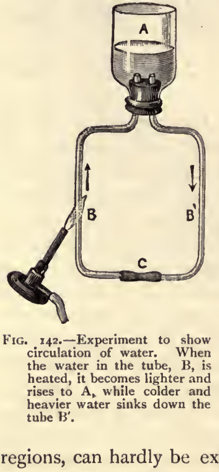

FIG. 142.—Experiment to show circulation of water. When the water in the tube, B, is heated, it becomes lighter and rises to A, while colder and heavier water sinks down the tube B'.

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[1] The freezing-point of water is lowered by the addition of common salt, and ordinary sea-water does not freeze until reduced to − 2° C. (28·4° F.).

equatorial regions. The cold polar waters sink by their density and form a deep layer, which creeps along the ocean-floor towards the equatorial regions; while the warmer and relatively lighter water floats on the surface in a contrary direction, or from equatorial towards polar areas. The character of this circulation will of course be greatly modified by the shape and depth of the sea-bottom over which the cold water creeps. Thus, the southern part of the Atlantic basin communicates freely with the Antarctic Sea, and the influx of cold water is therefore unimpeded; but the northern part of the basin is contracted, and the principal channel through which Arctic water can flow southwards is the shallow channel between Greenland and Iceland; hence the underflow of ice-cold water from the North will be much less than that from the South. This is still more strikingly shown by the shape of the great Pacific basin, where the communication with the Northern Polar seas is confined to the narrow and shallow channel of Bering's Strait, through which very little ice-cold water can flow to the south. By such means a complete circulation is established; and it has consequently been said that every drop of water in the open ocean may, in course of time, be brought up from the greatest depths to the surface.

Various causes of vertical circulation.—Other meteorological conditions, however, are capable of exerting an influence of the same kind as differences of temperature. Thus, where large rivers flow into the sea, and over parts of the ocean where an abundant rainfall is received, as in the western part of the Pacific, the density of the surface-water is diminished by the addition of so much fresh water. On the other hand, evaporation is much more rapid over some parts of the ocean than over others, and this again causes differences of density, the surface water being saltest and therefore heaviest, where the evaporation is greatest. As the ratio between the amount of rain received and the rate at which evaporation takes place varies in different parts of the earth, the density of surface water varies and circulation may be set up on this account.

Other influences, such as the formation of ice in polar regions and the melting of ice in lower latitudes, no doubt affect oceanic circulation, on account of the large amount of latent heat involved in the change, as already explained (p. 165). The effective agent, however, of ocean currents, and probably also the chief cause of the circulation of ocean water as a whole, is wind. It has been proved by actual measurement that the water driven into the Gulf of Mexico from the Caribbean Sea by the trade winds is heaped up above the general oceanic level. The Gulf of Mexico is thus a natural reservoir, and the water it contains runs out of the Straits of Bemini as the Gulf Stream.

Work of ocean currents.—It seems probable that ocean-currents are of no great importance as agents of denudation or of transport. A slow circulation of the entire mass of the ocean might perhaps facilitate the dispersion of the finest sedimentary matter. Again, where the surface-currents strike upon the shore they must do something in the work of denudation, though as a rule this will be extremely slight; the effect of currents, indeed, is not so much to abrade the land as to carry off the results of its abrasion by other means, and to distribute the finely-suspended matter far and wide over the floor of the ocean.

High and low water.—In addition to the movements of the sea which have been already noted in this chapter—the wind-waves, the surface-currents, and the general circulation—it must not be forgotten that the ocean is subject to the grand rhythmical movement of the tides. Twice in every four-and-twenty hours the margin of the sea rises, and twice it falls, so that its level is constantly shifting up and down. And yet it is a common practice to say that a given elevation is so many feet above the sea-level. Such a

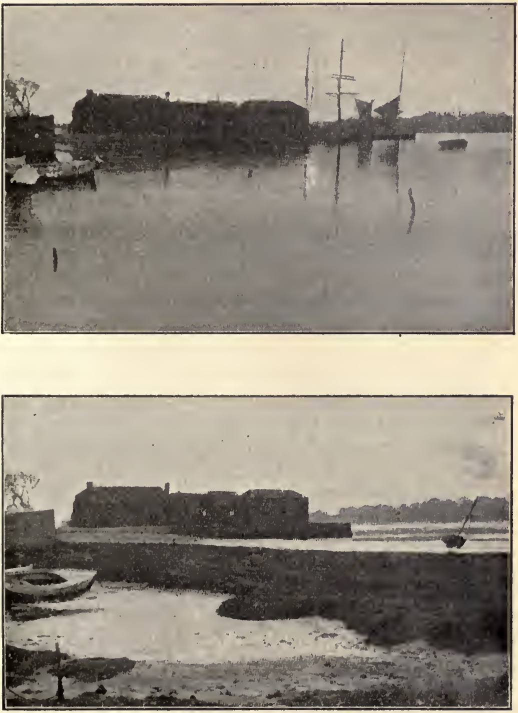

FIG. 143.—High and low water in a tidal creek—Dell Quay, near Chichester. The difference of level can be seen on the side of the quay. From photographs by Miss A. Tomlinson.

statement assumes that the standard taken is neither high-water mark nor low-water mark, but the mean level between the two; the water rising at one time as much above our standard level as it falls at another time below it. The Ordnance Survey has fixed its **datum line**, or standard from which all heights are measured, as the mean tide-level at Liverpool. The level of high water at London Bridge, which is sometimes taken as a standard, is called, from the Trinity House, "Trinity High-water mark."

Tidal waves.—As the cause of the tide is to be found outside our earth, its explanation must be deferred to a later portion of this work. It is sufficient to remark in this place, that the great tidal-wave, which travels round the earth, is an oscillatory wave and not a wave of translation, the water rising and falling, but not moving onwards. But in the formation of the tidal wave the water cannot be drawn only from below; some of the water from the sea all round must be drawn towards the wave so as to make, as it were, a mound. If the surface of the earth were an undivided ocean, the tidal mound would travel over it with little actual translation of water; for the water drawn towards the mound as it approached, would fall away into nearly its former position when the mound had passed the spot; and even though a great quantity of water would be swaying to and fro, the oscillation would be as smooth in proportion as the eddies on a pond.

Tidal currents.—Where land interrupts the tidal wave, the oscillation just described gives rise to currents alternately to and from the shore; and owing to the irregular outlines of the land, the tidal currents in many parts of the world are very complex, and often concentrated in particular localities. If a shallow or narrow passage, or "strait," intervene in the course of the currents, the tide may there produce a rapid rush of water or a **race**. Again, where the tidal current enters an estuary, there being no thoroughfare, the water becomes heaped up and produces a sudden rush into the channel of the river; and a converse effect is produced at the ebb of the tide. This is especially noticeable where an estuary is spacious at its mouth, but afterwards becomes narrow or shallow. Thus the Bristol Channel concentrates the tidal currents, making the rise and fall of the tide in certain seasons as much as 50 feet in the Wye near Chepstow: and a tidal current in the form of a great crested

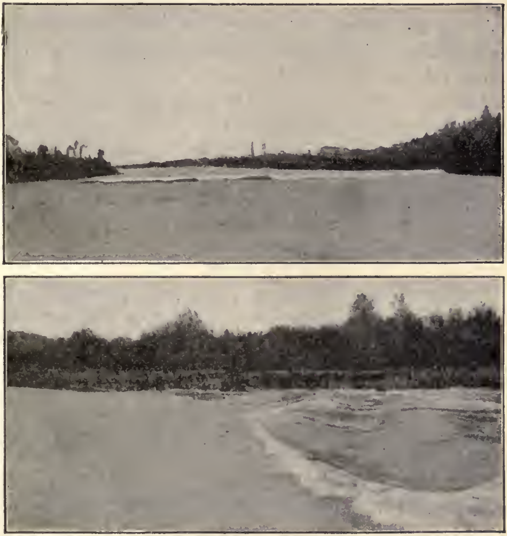

FIG. 144.—Severn bore, at Denny Pill. The upper view represents the bore approaching, in shallow water; the lower is a side view of the bore in deep water, about one minute later than the upper one. Reproduced by kind permission from photographs by Dr. Vaughan Cornish.

wave, known as a **bore**, rushes up the Severn so far as Gloucester.

Formation of bores.—The conditions necessary for the formation of a bore are a swiftly flowing river, a funnel-shaped estuary with a wide mouth to receive the tidal wave from the ocean, and a large expanse of flat sand or mud near the level of low water. The Severn possesses all these conditions, and the conflict between the rapidly rising tide and the flowing river produces the bore. The accompanying photographs of the approaching bore as viewed from a spot near Newnham, below Gloucester, give a good general view of the phenomenon (Fig. 144). The character of a bore does not, however, lie so much in the form of the rolling water as in the motion, which combines the ghost-like movement of a wave with the rushing steadiness of a railway train, and a roar that can be heard a mile away.

Sediment in relation to tides and currents.—In the estuary of a tidal river the tide periodically agitates the water, and thus hinders deposition of sediment. The flow of the river seawards is, however, checked every time the tide comes in, and sediment is then deposited; hence **bars**, or banks of sand, are common at the mouths of rivers; and even in the estuary of the Thames the shifting shoals indicate similar depositions. But it has been shown in a former chapter that the ebb-tide, by scouring out the estuary, prevents the formation of a true delta.

The sediment which the tidal water carries away from the mouth of a river at one part of the coast may be deposited at another point, and thus the sea may become a constructive agent charged with the formation of new land. Usually, however, the suspended matter swept away by the ebb-tide is carried out to sea, where it may be caught up by currents and thus drifted to a great distance. Hence the tides and currents assist greatly in distributing the solid matter derived from the waste of the land.

Tendency of marine waste.—Putting together what has been said in this chapter with reference to the action of the sea upon the land, it may be concluded that its work is on the whole a work of destruction, yet not exactly like that of rain and rivers. To observe this difference, it must be borne in mind that marine denudation is not equally active at all depths of the sea. The waves, as explained above, indicate only superficial agitation, and have no effect on deep water. Most of the destruction wrought by the sea is consequently confined within narrow limits, not extending deeper than a few hundred feet, and being for the most part restricted to the zone of coast between high and low water-marks. At great depths the abrasion by slow under-currents must be extremely small, for dredgings have shown that in deep seas there are no large fragments of rock to assist in the work of demolition; and even if there were, the force of the current would probably be insufficient to move them. The great business of the sea is therefore confined to eating away the margin of the coast, and planing it down to a depth of perhaps a hundred fathoms. If this action went on for a sufficient time, the entire coast would be nibbled away, and Britain reduced to a great plain below the sea-level. Were such a submarine plain to be upheaved above the surface of the water, it would immediately be attacked by rain, frost and other atmospheric agents, and would eventually be chiselled by these means into a variety of physical features. Denudation by the sea differs then from that effected by other agents, in that it tends to produce an approximately level surface, while subaerial denudation gives rise to superficial irregularities.

CHAPTER XI

MOVEMENTS OF THE LAND

I. Slow Movements

Destructive agencies.—All the natural agents described in the three previous chapters, however much they may differ among themselves, agree in this—that they are, upon the whole, slow and certain agents of destruction. Rain and river, frost and thaw, wind and wave—all work in the same direction, persistently attacking the solid land and sweeping away its superficial substance. Not that a particle of this substance is annihilated. Every grain stolen from the land is sooner or later carefully deposited somewhere in the sea. But still this gradual transference of matter, from land to water, must ultimately result in the lowering of the general level of the land to that of the sea, by the action of rain and rivers; and in the subsequent paring down of the plain thus formed, to the depth at which marine denudation becomes insensible. If, therefore, no hindrance were offered to the action of these agents, not only would a time come when every foot of the British Isles would be buried beneath the sea; but inasmuch as the volume of the sea is very much greater than that of the land which rises above the sea-level, if sufficient time were granted, all the dry land in the world would ultimately disappear beneath one universal sheet of water.

It is not difficult, however, to detect in the operations of nature counterbalancing forces, which are capable of upheaving the deposits that have been formed on the sea-bottom, and of piling up fresh stores of solid matter upon the surface of the earth.

Rise and fall of land.—It will be shown presently that a large part of southern and eastern Britain has evidently, at some time or other, been buried beneath the sea; also that the same may be inferred of the rest of the British Isles, though the evidences are not everywhere so conspicuous: it is therefore clear that elevatory forces must have been at work to lift up the sea-bed and expose it as dry land. Nor has such movement been effected once only Any one who seeks to read the history of the rocks will be forced to conclude that the level of the land has changed again and again, rising at one time and falling at another. Probably such changes have been effected for the most part quietly rather than violently; by slowly-acting forces working through long periods of time, rather than by sudden disturbances.

The land is subject not only to sudden rises and falls such as accompany earthquakes, but also to local elevations and depressions so gradual as to escape ordinary observation; and it is probable that such gradual oscillations of the land are, in the long run, of far greater importance in the economy of nature than those abrupt movements which occur only at intervals.

Oscillations of land.—The coast in the neighbourhood of the Bay of Naples,[1] that is, near the foot of Vesuvius, shows unmistakable signs of having changed its level more than once, although the changes have been so gradual that the inhabitants have not been conscious of the movement, but have only noticed its effect in an apparent change in the water-line. Many of the rocks are marked with lines of wave-erosion at various heights above the present water-level, the greatest difference being as much as 23 ft.; again, the ruins of many ancient buildings lie under the water, their bases being sometimes as much as 17 ft. beneath the surface. It is clear that when the buildings were erected the ground on which they stood must have been at least 17 ft. higher than at present; while at some other time it must have been lower, as much as 23 ft. lower in some places; the difference between the extremes of level being 40 ft.

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[1] "Earth-movements in the Bay of Naples." By R. T. Günther. *Geographical Journal*, August and September, 1903.

The evidence of change of level was first noticed in the ruins of the so-called Temple of Serapis at Pozzuoli. The base of this building is now covered with water; but three tall marble columns stand to a height of some 40 ft. above the water. These columns nevertheless show signs of having been formerly immersed several feet deeper than at present. A very noteworthy feature is, that at a height of more than twelve feet from the ground the columns are marked with holes made by a rock-boring shellfish, such as inhabits the neighbouring sea. These holes are quite characteristic, being pear-shaped depressions, at the bottom of which the little animal dwells, and where its mussel-like shell remains after its death.

The so-called temple was of course built above the sea-level, but has evidently been submerged beyond the holes bored by the molluscs, and been again raised. In fact it was well above water at the beginning of the nineteenth century, and has since then sunk again to its present level.

It needs scarcely a moment's consideration to show that these effects cannot be attributed to changes in the sea-level; for the marks of the former wave-erosion are at different heights on different rocks and buildings, whereas we know that water, whether it rose or fell, would retain a level surface, except for the oscillation of the tide; and the tide in the Mediterranean is so slight as to be quite inadequate to account for such differences.

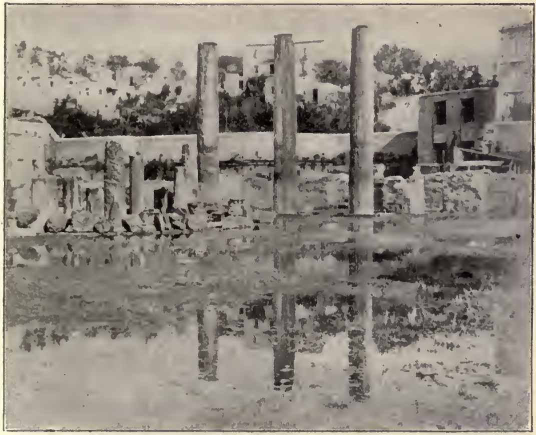

FIG. 145.—Temple of Serapis, Pozzuoli. October, 1903. From a photograph by Prof. H. J. Johnston-Lavis.

Slow changes of level.—Slow movements of the land are by no means confined to regions subject to volcanic disturbances. Few countries in the world, perhaps, have been more free from such disturbances than Scandinavia. Yet direct measurement has shown that the northern part of this peninsula is slowly rising, while the southern part, curiously enough, appears to be suffering depression. In such a case as this, where movements in opposite directions are simultaneously going on, it is useless to think of attributing them to any movement of the sea. For a change of sea-level implies a general change, whether of rise or fall; and it is therefore absurd to assume a rise in one place and a fall in another at the same time.

Submerged valleys.—The long arms of the sea which penetrate the mountainous ridge on the west coast of Norway for distances up to about one hundred miles, afford evidence of the depression of land. It is believed that these **fiords** were carved out by the action of glaciers and rivers when the table-topped mountains or **fields** of Scandinavia were protected by imperfectly consolidated snow or névé (p. 169). Since that epoch the land has been depressed and the sea has been admitted into the deep gorges produced by glacial erosion. The fiords of Norway thus represent submerged mountain valleys; and the long lochs on the west coast of Scotland are of the same character.

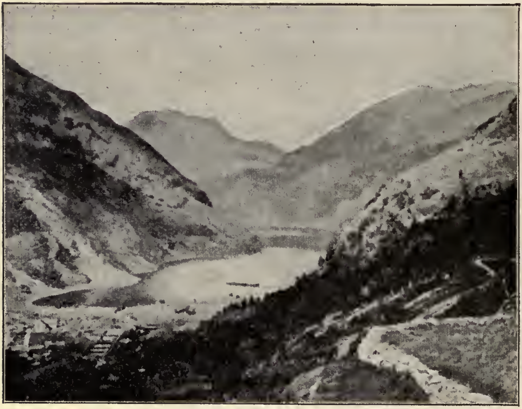

FIG. 146.—Head of Geiranger-Fiord, Norway. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

Inland lochs, such as Loch Lomond and Loch Maree, would in a similar way be converted into fiords by the depression of land near their basins below sea-level.

Evidence of elevation.—In the British Isles there is no lack of evidence to show that the level of the land has been frequently disturbed, though the oscillations within the memory of man are hardly so well marked as in the cases previously cited. Visitors to certain parts of the coast of Britain may note a terrace of sand and gravel, mixed perhaps with sea-shells, and having all the appearance of a deserted beach, which fringes the shore at a height far beyond reach of the highest tides. Such accumulations must have been formed along a line of shore, and afterwards elevated to their present position, whence they are termed **raised beaches.** A raised beach is therefore an index of

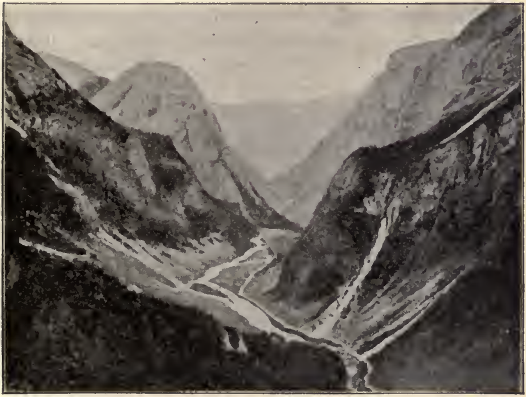

FIG. 147.—The Närö-dal, Norway: an ancient glacier valley which becomes a fiord at its lower end. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

elevation of the land. And it appears that this elevation must have been effected, in part at least, since the country was inhabited. For the upraised deposits of silt which skirt the estuary of the Clyde have yielded relics of human workmanship, such as rude canoes, that were originally buried in the mud and sand of the old estuary, though they are now found several feet above high-water mark.

Submerged forests.—Evidence of the depression of land in Britain is just as conclusive as that of elevation. It is sometimes possible to see at low tide, in the estuary of the Thames, the remains of a vast forest, with the stools or stumps of the trees still rooted in the old soil, now submerged to a depth of perhaps twenty or thirty feet below high-water. The relics of this ancient forest show that it must have supported a rich growth of yew, pine, oak, alder, and other trees. Now, as these trees do not grow in water, it is evident that the land on which they flourished has been depressed. It is not, however, only at the mouth of the Thames that such evidence of subsidence is to be found; for similar submerged forests may be seen at low water at

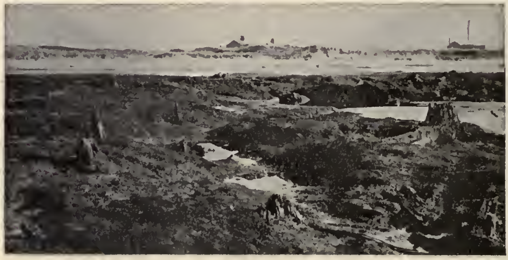

FIG. 148.—Forest bed at Leasowe, Cheshire, made up of peat, upright stools of trees, and roots of the oak, fir, birch, and other trees. The bed is under 6 feet of water at high tide. Photographed by Mr. C. A. Defieux.

many points of the British coast, especially in Devon, Cornwall, Wales, and the Leasowe Shore, Cheshire (Fig. 148).

Land once under water.—Raised beaches and submarine forests are not the only evidence which the geologist can cite to prove that the surface of the British Isles has suffered frequent changes of level. Nor are they by any means the strongest. Indeed, their value lies chiefly in the fact that the movements which they register are of comparatively recent date. That there have been variations of level to a much greater extent at more remote periods is abundantly testified by the strata in almost any part of the country. For example, London is seated on clay which, as already pointed out, must have been deposited under water in the state of mud. But as in many parts this clay contains the remains of marine shell-fish, such as the nautilus, there can be no doubt that the mud in such places must have been originally thrown down out at sea. The clays, sands, and other deposits below the London clay, already referred to under the name of the Lower London Tertiaries (p. 27), have been formed, some in salt and others in brackish water, as is testified by the character of the shells which they contain. As to the chalk, which lies in a mass of vast thickness immediately beneath these deposits, it will be shown in a subsequent chapter that it abounds with the remains of creatures which once lived in the depths of the sea. If, then, these rocks are for the most part old sea-bottoms, it is clear that great upward movement must have taken place to raise them into their present situation.

Horizontal and contorted strata.—The rocks have not only been uplifted, but in many cases have been subjected to some disturbing action by which they have been more or less contorted. The section in Fig. 24, p. 26, shows that the strata beneath London lie in a gentle hollow, purposely exaggerated in the diagram, but still sufficiently marked in nature to suggest the name of "London Basin." Sup-

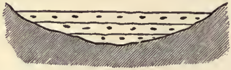

FIG. 149.—Strata deposited in a basin.

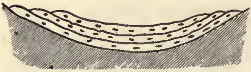

FIG. 150.—Strata thrown into a basin-shape.

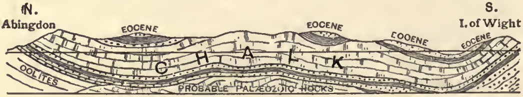

FIG. 151.—Section from Abingdon to the Isle of Wight. Vertical to horizontal scale as 20 to 1.

posing they had been originally deposited in a depression of the sea-bottom, the layers would have been thrown down almost horizontally, as in Fig. 149, and not in curved layers of equal thickness as in Fig. 150, such as are really found in nature. The present position of these rocks is therefore explained by supposing that the strata were originally horizontal, and have been thrown into a basin-like shape since their formation. The disturbance to which they have been subjected is yet more strikingly seen if a section be taken across, not only this basin, but across another area of similar character, known as the Hampshire basin. Fig. 151 is a section from Abingdon in Berkshire, through Hampshire and across the Solent to the Isle of Wight, the vertical scale being about twenty times greater than the horizontal scale. Here the strata, originally almost horizontal, have been thrown into a succession of gentle undulations, rising to a crest in one locality and falling to a trough at another. There can be little doubt that the Eocene rocks, including the London clay, once spread over the whole surface of this chalk, but have since been removed from the high ground by denudation, leaving isolated tracts separated by intervening patches of bare chalk. In the Isle of Wight the beds have been so greatly disturbed that the chalk strata stand almost on end, as is well shown by the bands of black flints which run in almost vertical lines (Fig. 152). Incidentally it may be remarked that when

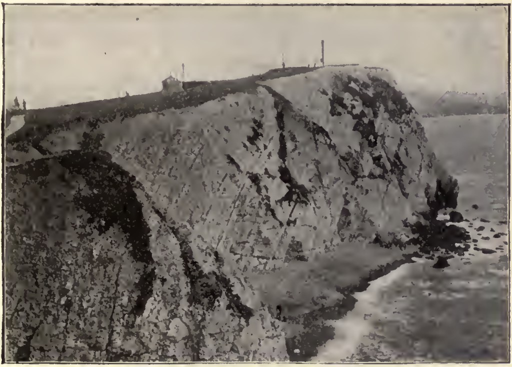

FIG. 152.—High Down, near Freshwater Bay, Isle of Wight. Chalk cliffs with nearly vertical bands of flint. From a photograph by Mr. W. Jerome Harrison.

strata lie in this shape ⌣ they are said to form a **synclinal**,[1] and when in this form ⌢ an **anticlinal**.[2] The strata in the south-eastern part of England have been but little disturbed; but, among the old rocks of Wales and other parts of western Britain, it is not uncommon to find the beds thrown into a succession of sharp anticlinals and synclinals, the strata being sometimes doubled up or even inverted (Fig. 153).

Broken strata.—During the disturbances to which strata have been subjected since their original deposition, it has frequently happened that the rocks have been broken and dislocated, as represented in Fig. 23, p. 25; where the series of beds, on one side of the fracture or fault, have been thrown down to a much lower level than that occupied by the strata on the opposite side. Even in an area so little disturbed as the London basin, such dislocations of the strata may be detected; and indeed a considerable fault runs along part of the valley of the Thames below London, the beds on the north being thrown down to the extent of 100 feet, or even more.

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[1] *Synclinal*, from σὺν, *syn*, with; and κλίνω, *klino*, I lean.

[2] *Anticlinal*, from ἀντὶ, *anti*, against; and κλίνω.

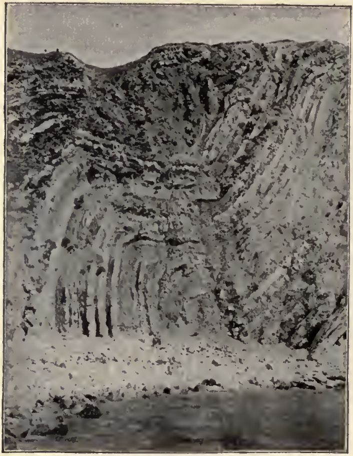

Fig. 153.—Stair Hole, Lulworth, Dorset. Contorted limestones and shales. From a photograph by Mr. W. Jerome Harrison.

Rock folding by pressure.—By careful examination of disturbed strata we learn that they have very seldom been lifted by pressure from below, but nearly always by lateral pressure, the rocks having been squeezed into a smaller—sometimes much smaller—area than they previously covered. It is evident that the rocks would yield to lateral pressure by bending at the places of greatest stress or greatest weakness; also that the folds would be most pronounced in the upward direction, that being the direction of least resistance (Fig. 154). The folding has been attended with various degrees of elevation, over-riding, fracture, crushing, and even melting. The phenomena can be imitated on a small scale by applying pressure to the sides of a pile of cards; when it will be seen that the cards rise in the middle, and become crumpled, cracked, or disintegrated, according to the degree of compression. To make the experiment more complete, the cards should rest on a firm cushion, allowing a limited movement downward: for the internal substance of the earth is able to yield in a measure to downward pressure, so that some regions of the folding strata move downwards, though seldom to the same degree as the other regions escape upwards.

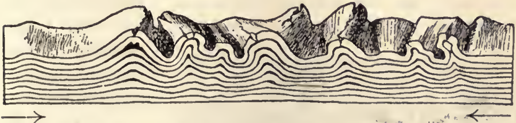

FIG. 154.—Folds produced in layers of clay by the contraction of an indiarubber band upon which the clay rested.

The chief cause of lateral compression of the rocks is believed to be as follows:—The interior of the earth is at a high temperature,[1] but is constantly losing heat by conduction through the crust into space. As the temperature falls the interior shrinks: but the crust does not shrink correspondingly, for its temperature remains nearly constant. The result is, that the crust is always larger than the foundation it rests on; so there must always be lateral pressure, which makes itself felt by folding and crushing the weaker regions.

Torn rocks.—But while the average result is compression, there are some points where stretching occurs, with production of rents and underminings, and consequent subsidence of surface. Stretching movements are specially liable to cause **faults**, in contrast to the *crushing* produced by compression. For, when a rent is formed, the separated rocks fall into new positions with their strata dislocated or "faulted." The mechanism of stretching movements is less easy to understand than that of crushing movements, especially when the stretching occurs on a large scale: but in any case crushing predominates in the earth's crust; and stretching in one direction is generally secondary to compression in another. It should be understood that the secular contraction of a globe cooling in space does not provide an adequate explanation of all the movements of elevation and depression of the earth's crust, but a discussion of the subject in detail is beyond the province of this book.[1]

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[1] To be explained in next chapter.

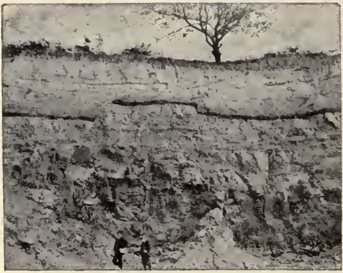

FIG. 155.—Faulted coal-seam near Nottingham. Reproduced, by kind permission, from a photograph by Dr. F. J. Allen.

The movements of the crust are probably modified by the gravitation of the sun and moon, for the land is subject to the same alternations of attraction that produce the tides in the sea. No doubt the effects on the land are incomparably smaller than those on the ocean; nevertheless in the course of ages the small effects may accumulate, determining in some measure the direction in which the crust shall shift.

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[1] Other causes capable of producing the various land forms are described by Mr. Mellard Reade in *The Evolution of Earth Structure, with a Theory of Geomorphic Changes.* (Longmans, 1903.)

CHAPTER XII

MOVEMENTS OF THE LAND (*continued*)

II. EARTHQUAKES AND VOLCANOES

Sudden fractures of land.—While the folding movements of the land, as described in the previous chapter, go on for the most part unobtrusively, it happens now and again that the pressure, or sometimes tension, accumulates until it becomes relieved by a sudden slip or fracture at a weak spot. The resulting sudden movement is felt as an

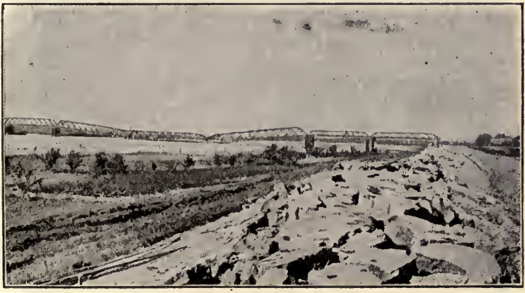

FIG. 156.—Railway bridge and embankment broken by an earthquake. From *The Great Earthquakes in Japan*, by Profs. J. Milne and W. K. Burton.

earthquake, and a permanent change is often produced in the surface of the land. The change, though invisible in milder cases, is unmistakable after a severe earthquake. For example, the whole of the disturbed rocks may be shifted upwards; or one part may move up and another down; or again, the movement may be sideways, one part sliding against another.

During a severe earthquake in Japan in 1891 a great fault, forty miles long, was formed in the valley of Neo. On one side of this fault the ground subsided in places nearly twenty feet and was also displaced horizontally. Apart from the destruction of towns and buildings, the result of the earthquake was greatly to modify the physical geography of an extensive area, changing the courses of streams and their rate of flow, forming swamps, and in many ways accelerating the gentler processes of surface change by erosion. Similar displacements were caused by the Assam

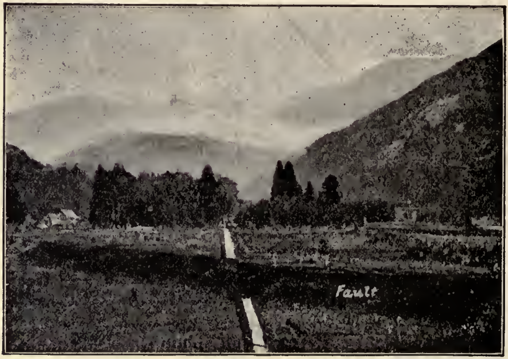

FIG. 157.—Fault caused by the great Japanese earthquake of October, 1891. From the *Geographical Journal.*

earthquake of 1897, no less than ten thousand square miles of country being affected by this disturbance.

Upheaval of land.—But more pronounced than the changes of relative level on opposite sides of a fissure (Fig. 157), and the effect of lateral compression (Fig. 158), though not so easily represented pictorially, is the upward movement which sometimes occurs over extensive areas. Perhaps the best recorded example of such upheaval is that which was observed by Admiral Fitzroy and Charles Darwin when examining the western coast of South America. This region is peculiarly subject to subterranean disturbances, and in 1835 a violent earthquake, which destroyed several towns, was felt along the coast of Chile, extending from Copiapo

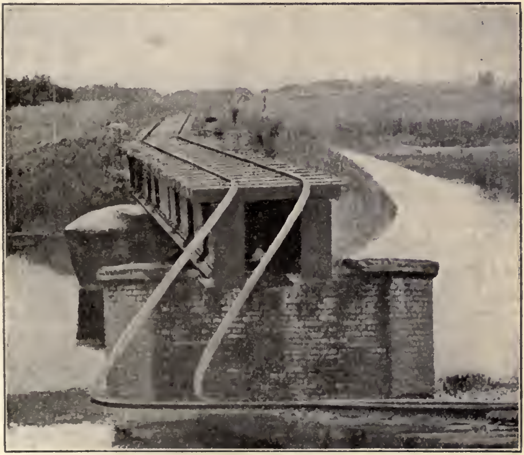

FIG. 158.—Effect of the Indian earthquake of June 12, 1897. From a report of the Survey of India.

to Chiloe. It was found, after the shock, that the land in the Bay of Concepcion had been elevated to the extent of four or five feet. At an island called Santa Maria, about twenty-five miles south-west of Concepcion, the upheaval was easily measured, vertically, on the steep cliffs; and the measurements showed that the south-western part of the island was raised eight feet, while the northern end was lifted more than ten feet high. Beds of dead mussels were, in fact, hoisted ten feet above high water mark; and an extensive rocky flat, previously covered by the sea, was exposed as dry land. In like manner, the bottom of the surrounding sea must have been elevated, for soundings all round the island became shallower by about nine feet. It is true there was a partial subsidence shortly afterwards, but this was far from sufficient to neutralise the upheaval, and the net result showed a permanent elevation. It is considered probable that the greater part of the South American coast has been raised several hundred feet by a succession of such small upheavals.

New land.—When an area is thus raised, the addition suddenly made to the mass of dry land may be very considerable, and will compensate for the effects of denudation continued through a long period. For example, during an earthquake which occurred in Chile in 1822, 100,000 square miles were permanently lifted about four feet, which means that about fifty-seven cubic miles of material were added to the South-American continent. If a single convulsion of this kind can thus raise such an amount of solid land from beneath the waters, it is obvious that these movements must be of great service in renovating the surface of the earth, and in bringing new material within reach of the ever-active agents of denudation. Several similar instances have been recorded; thus, as the result of the Cutch earthquake of 1819, two thousand square miles of land were converted into an inland sea, while at the same time a strip of land fifty miles long and ten miles broad was elevated ten feet.

Study of earthquakes.—In the middle of the last century a good deal of attention was paid by R. Mallet to the study of earthquake phenomena, or **Seismology,**[1] and more recently the subject has been studied minutely by Prof. J. Milne and others. In Japan, where earthquakes are very frequent, much information has been acquired through systematic observations and experiments carried on under the auspices of the Japanese Government.

In the investigation of earthquakes, sensitive instruments called **seismometers** are used. These are affected even by very slight movements of the ground on which they are fixed; and when a shock occurs the seismometers automatically make tracings on photographic paper, or a smoked surface, showing the direction and intensity of the movements, and the exact time of their occurrence.

Two causes of earthquakes.—While the greater earthquakes may be attributed to the rock-folding movements already mentioned, many minor earthquakes are believed to be produced by steam, which may accumulate at great pressure in some closed space, until at last it overcomes the resistance and bursts into some subterranean fissure. Sudden escapes of steam seem to occur also on the floor of the sea, in which case very sharp and noisy concussions are produced; for the steam first suddenly expands, and is then suddenly condensed by contact with the cold water, so that a double movement is the result. But though escapes of steam, whether under water or under ground, can cause such sharp vibrations as to do serious damage to buildings, they are not likely to produce permanent changes of level in the rocks.

Land waves caused by shock.—When a sudden movement of the land occurs, whether through slipping of the rocks, escape of steam, or other causes unknown, the shock spreads in all directions in the form of waves: for the rocks, however rigid they may seem, are nevertheless capable of slight compression, stretching, and bending; being elastic, however, they spring back to their original form, but spring too far, and thus oscillate like any other elastic substance until the energy of the shock is dispersed. Thus these earth movements are comparable with sound waves produced by concussion of the air, though it is of interest that earth waves travel much faster than air waves. Sometimes the earth waves, being communicated to the air also, are audible as a rumbling noise, resembling distant thunder.

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[1] From σεισμὸς, *seismos*, a shock or earthquake.

Sea waves caused by earthquake.—When an earthquake affects the floor of the sea, great oscillations of the water may be generated; and these, when they reach the shore, may form huge breaking waves which do more damage than the earthquake on which they follow. This was the case in the great earthquake of Lisbon in 1755; and in June, 1896, the coast of Japan was devastated by three great waves, the largest being about fifty feet in height, which caused the destruction of twenty thousand lives and twelve thousand buildings in a few minutes. The earthquake which gave rise to the latter waves originated in a deep trough of the ocean floor, known as the Tuscarora deep, a short distance from Japan; and the tide-gauges at Honolulu and Sausalito (San Francisco), which are 3,590 and 4,790 miles from the point of origin, recorded the disturbance of the sea 7hrs. 44min. and 10hrs. 34min. respectively after the time at which the earthquake occurred.

Earthquake autographs.—An extraordinary wave which overwhelmed many of the Society Islands in January, 1903, seems also to have had its origin in an earthquake, for a disturbance competent to produce such an effect was registered by instruments in Prof. Milne's seismological station in the Isle of Wight. The records thus obtained showed that a great earthquake or eruption on the ocean floor occurred at a distance of about 137° from the Isle of Wight, and therefore probably to the east of Tahiti—where the great sea wave occurred—on the day of the disaster.

A large earthquake gives rise to a series of waves which travel through the earth and around its surface. The first indication of an earthquake recorded by seismometers consists of a group of movements, known as preliminary tremors, which travel *along straight lines through the interior* of the earth with a velocity of about 5½ miles per second, and therefore pass from one side of the earth to the other, along a diameter, in about twenty-two minutes. The tremors represent the shortest waves. and their velocity is practically constant: they are followed by longer waves, and these are succeeded by the largest kind of earthquake waves, which travel *around* the earth from the centre of disturbance with a velocity of nearly two miles a second. Prof. Milne's observa-

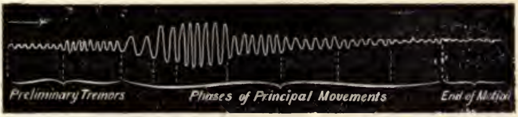

FIG. 159.—Typical diagram of successive phases of earthquake motion recorded by a seismometer. (Omori.)

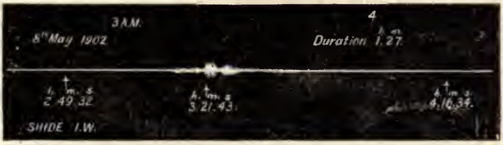

FIG. 160.—Record of the eruption of Mont Pelée on May 8, 1902, obtained by Prof. J. Milne in the Isle of Wight.

tions show that preliminary tremors reach a place 80° from their origin in about fifteen minutes, whilst the large waves take about fifty minutes. By noticing the interval between the arrival of the two kinds of movement, it is thus possible to determine the approximate distance of the disturbance from the observing station.

Frequency of earthquakes.—Although earthquakes which cause perceptible movements of the ground or buildings are happily rare in our own country, there are many parts of the world, Japan, for instance, where they are of frequent occurrence. About fifty earthquakes which shake the whole mass of the earth occur every year; and the regions in which they originate can be discovered by reading the messages they write upon suitable recording instruments.

Readjustments of furrow and ridge either on land or under ocean water usually accompany these world-shaking earthquakes, and they often lead to outbursts of volcanic activity. There are, however, about ten thousand small earthquakes every year in various parts of the world, and these do not seem to bear any relationship to volcanic action.

Even in England we are occasionally reminded that the solid land beneath us may be shaken by the slipping or shifting of great masses of rock at one point. During an earthquake on December 17, 1896, injury was done to buildings within a region containing about four thousand square miles, and extending from Tortworth (Gloucester) to Manchester. The rate of progress of the earthquake wave appears to have been about thirty miles a minute from Hereford as a centre.

Depth of disturbance.—One of the results of seismological investigations has been to show that the origin of the disturbance is usually not deep-seated in the interior of the earth. In most cases where data have been available for calculation, the depth has been found to be between two and ten miles. In rarer instances the depth has been calculated as considerably deeper, even up to fifty miles: but even so, this is but a very small fraction of the earth's diameter.

Permanence of ocean floors.—The floor of the deep ocean, so far as it has been investigated by soundings,[1] shows but little evidence of the folding and crushing which are so unmistakable in the dry land. In fact it appears that the effects of earth movements have always been concentrated in the land areas and the shallow seas, while the beds of the deep oceans have been but little disturbed. In other words, the higher parts of the earth's surface, though repeatedly raised above the sea and immersed again, have never been carried to the lowest depths; nor has the floor of the deepest oceans ever been raised above water. The principal land areas and ocean areas have thus not changed their relative positions since the time when they first began to be differentiated one from the other.

This state of things is in accord with the accepted theory of the folding of the earth's crust as the result of the shrinking of the interior. It was explained on page 223 that when the weak spots yield to pressure they must shift mostly upward; but the land and shallow sea are formed of just the weak parts which have risen in this way. Again, when once a weak part has given way, every subsequent stress that occurs in the crust must tend to find relief by further yielding of the same weak part; just as, after an egg has been cracked, pressure applied to any part of the shell causes further yielding of the cracked spot. Thus the land bears the brunt, not only of the disturbances belonging to itself, but also of the stresses conveyed to it by the unyielding bed of the ocean.

Distribution of volcanoes and earthquakes.—Those parts of the world where great movements of the land are in progress are often, though not always, characterised by the presence of volcanoes. For instance, the shores of the Mediterranean Sea are subject to earthquakes as well as to slow movements, and near its centre are the volcanoes of Etna, Vesuvius, and the Lipari Islands. Japan is a land of earthquakes and volcanoes; and South America, where the greatest land movements have been observed, has many volcanoes, among which Cotopaxi is the most familiar by name. Though eruptions have long since ceased in Britain, the rocks of our islands, especially in the north and west, show evidence of great volcanic activity associated with great movements in former geological periods.

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[1] See further in Chapters XIV. to XVI.

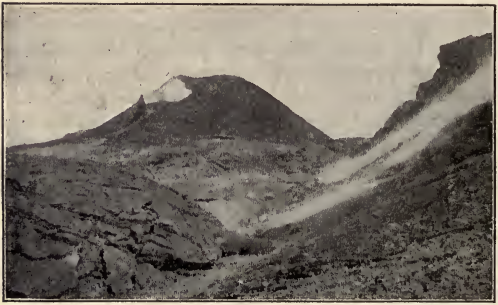

Photo. *Sommer, Naples.*

FIG. 161.—Vesuvius in the year 1880.

In fact, a volcano is probably an extreme result of earth movements. It seems that in places where the rocks have been intensely displaced and crushed, a rupture may be made to such a depth as to give exit to melted rock, steam and gases, from the deeper parts of the earth. The origin of this material and the cause of its heat will be considered later: for the present it will be profitable to note the phenomena of an eruption.

Volcanic eruptions.—After preliminary warnings in the form of earthquakes, the eruption begins with the escape of large volumes of steam and other gases, with showers of dust and hot **volcanic ash**, accompanied or followed by streams of molten rock, known as **lava.** The ejected materials accumulate around the orifice, where they form a cone-shaped mound or hill. Such a hill is called a **volcano**,[1] or popularly a "burning mountain." It must be borne in mind, however, that it does not "burn" in the sense in which a fire burns, but it merely offers a channel through which heated matter is erupted from below. It differs again from an ordinary mountain, in that it is simply a heap of loose materials and once melted matter, which has been piled up, layer after layer, around a hole leading down to the interior of the earth.

Structure of a volcano.—If a volcano were cut through, it would probably present a section something like that shown in Fig. 162. Here a channel has been opened through strata originally horizontal, and the ejected matter has fallen all round the orifice in conical layers, each forming a mantle thrown irregularly over the preceding layer, and sloping in all directions away from the central chimney.

At the mouth of the volcanic pipe there is usually a funnel-shaped opening known as the **crater.** Fragmentary materials falling back into this cup, or rolling in from the sides, form layers which slope *towards* the vent, and therefore in the opposite direction to the dip of the volcanic beds which make up the mass of the mound. The molten matter which wells up the throat of a volcano cements the loose ashes and cinders into a compact mass, where it comes in contact with them, and thus forms a hard stony tube lining the volcanic chimney.

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[1] *Volcano*, Italian *vulcano*, from Vulcan, the Roman god of fire.

Phenomena of a volcanic eruption.—At the beginning of an eruption, clouds of steam are copiously belched forth, showing that water has its part to play even in these fiery phenomena (Fig. 163). The steam generally issues spasmodically, each puff giving rise to clouds which shoot up to a great height, and are either dissipated or condensed in torrents of rain. Associated with the steam are various gaseous exhalations, most of which, however, are not combustible. Hence the appearance of a column of flame, often said to be seen issuing from a volcano, must generally be an illusion, due to illumination of the vapours, partly by the red-hot stones and ashes shot out at the same time, and partly by reflection from the glowing walls of the pipe and from the surface of the molten matter below. In the early stages of an eruption, huge fragments

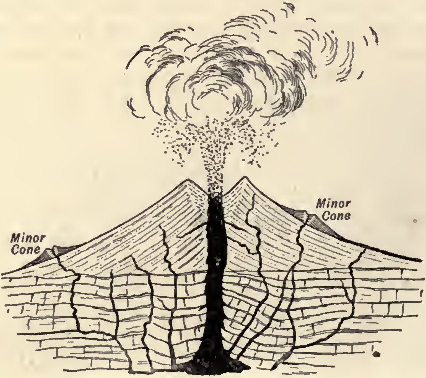

FIG. 162.—Diagrammatic section of a volcano, showing dykes and minor cones.

of rock may be ejected; for when, after a period of repose, the pent-up steam and gases at last gain vent, they violently eject the materials which have accumulated in the throat of the chimney and choked its opening. Masses of rock, some as much as nine feet in diameter, are said to have been cast forth from the great volcano Cotopaxi, in Quito, during the eruption of 1553, and to have been hurled to a distance of more than fifteen miles from the mountain.

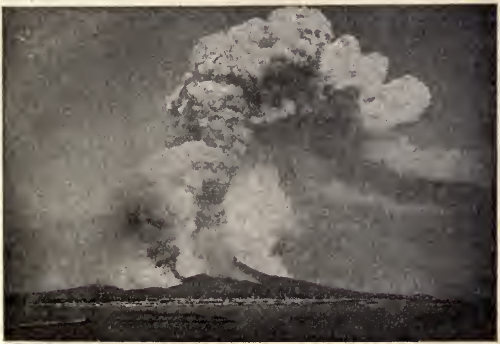

Photo. *Sommer, Naples.*

FIG. 163.—Eruption of Vesuvius in 1872.

At the beginning of the tremendous eruption of Krakatoa in Java, which occurred in 1883, a mass of rock calculated to measure something like a cubic mile was suddenly dislodged by the explosive expansion of steam and gases. The rock, falling into the sea, caused a wave which wrought disaster on the neighbouring coasts. The sound of the explosion was heard as far off as Queensland, 3,000 miles distant; and the concussion which it caused in the atmosphere was recorded by barometers in all parts of the world.

Volcanic ash and dust.—During an eruption, ashes are commonly ejected in great quantity, but it must be borne in mind that the materials so called are very different from the partially-burnt fuel of the domestic hearth. Volcanic

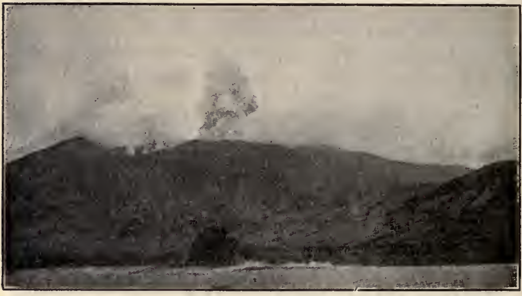

FIG. 164.—A puff from the Soufrière, St. Vincent, March 3, 1903. Photographed for the American Museum of Natural History by Prof. E. O. Hovey, and reproduced by kind permission of the Museum.

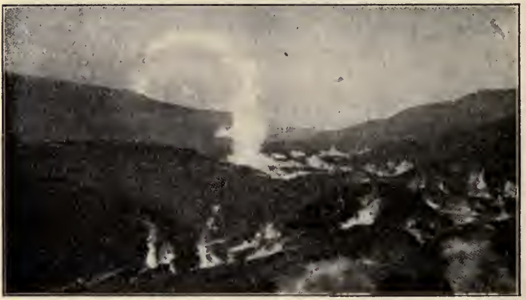

FIG. 165.—Steam escaping from beds of volcanic ash flowing down the flanks of the Soufrière. Photographed for the American Museum of Natural History by Prof. E. O. Hovey, and reproduced by kind permission of the Museum.

ashes are, in fact, nothing but fragments of lava, or partially-fused rocky matter, rendered porous by the presence of steam. When lumps of this lava are shot forth from the volcano, the liquid is broken up by the rapid motion, and cooled by contact with air, so that it falls in the form of spongy fragments, resembling ashes and cinders. In some cases, generally by the sudden expansion of steam between its particles, the lava is broken to fine dust. In the course of the eruptions of Mont Pelée in Martinique, West Indies, in May, 1902, the town of St. Pierre was destroyed, and all its inhabitants save one suffocated, by a sudden outburst of scalding vapour and gas loaded with such dust.

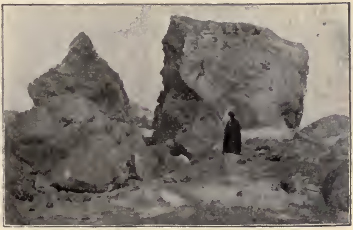

FIG. 166.—Block ejected from Mont Pelée during the eruption of May 8, 1902, and projected to a distance of 1½ miles from the crater. Photographed for the American Museum of Natural History by Prof. E. O. Hovey, and reproduced by kind permission of the Museum.

Dense clouds of dust have been known to darken the sky for miles around a volcano, and have been wafted by winds for even hundreds of miles. It is an interesting fact, shown by the examination of the sea-bottom by the *Challenger* expedition, that volcanic detritus is almost universally distributed over the floor of the deep sea.

During the eruptions of Mont Pelée already mentioned, and of the Soufrière on the neighbouring island of St. Vincent, which occurred at the same time, the dust fell thickly on other islands of the group, as well as on the sea. For instance, on Barbados, 100 miles to windward, the quantity which fell was several tons to the acre. Two views of some of these dust particles, photographed with a microscope magnifying them by about eight times their linear

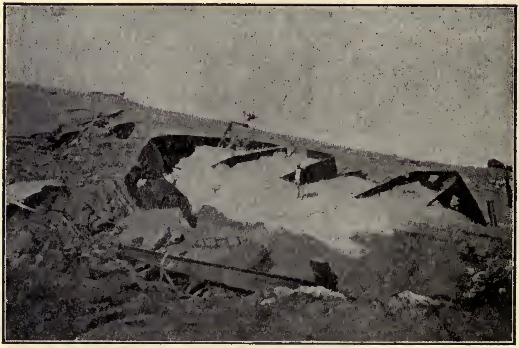

FIG. 167.—Ruins of a great distillery at St. Pierre, showing the holes in the iron tanks due to masses ejected from Mont Pelée during the eruption of May 8, 1902. Photographed for the American Museum of Natural History by Prof. E. O. Hovey, and reproduced by kind permission of the Museum

measure, are shown in Fig. 168. In one of the pictures the particles were illuminated from above, and in the other the light shone through them from below, so that the difference of transparency of the particles can be seen.

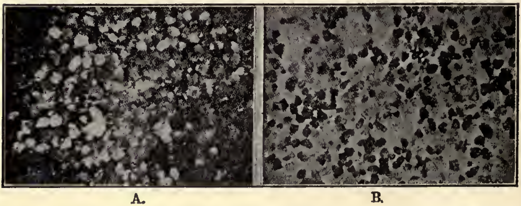

FIG. 168.—Volcanic dust particles from the Soufrière, collected at Barbados. Magnified about eight diameters. A, view by reflected light; B, by transmitted light. Reproduced, by kind permission, from photographs by Mr. T. C. Porter.

The finest particles of dust remain suspended for weeks or even months in the atmosphere and may be conveyed by wind to all parts of the world. The action of this dust upon sunlight gives rise to remarkable sunrise and sunset effects, such as were seen after the eruption of Krakatoa in 1883 and the West Indian eruptions in 1902.

When the steam, which is abundant in most eruptions, condenses in torrents of rain, the volcanic dust is frequently worked up into a hot mud which rolls down the hill in a sluggish stream, burying everything before it. Herculaneum was sealed up by a crust of volcanic mud discharged from Vesuvius; while Pompeii was overwhelmed by a vast accumulation of dust and ashes during the same eruption.

Lavas.—The partially-molten rock called **lava** rises up in the volcanic pipe, and may eventually run over the lip of the crater, or force its way through cracks in the hill, forming red-hot streams which generally present a consistence something like that of treacle. These lava torrents are often of great magnitude; thus, it was estimated that in the famous eruption of Skaptár Jökull[1] in Iceland, in 1783, the mass of lava brought up from subterranean regions was equal to the bulk of Mont Blanc. The lava rapidly cools on the surface, though long retaining its heat beneath the protecting crust; and ultimately the entire mass solidifies, forming a hard rock, more or less like a slag from an iron-furnace.

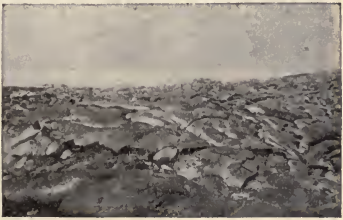

Photo. *G. W. Wilson.*

FIG. 169.—Lava in the crater of Kilauea, Hawaii.

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[1] The pronunciation is approximately Yeckūll.

In different specimens, however, the lava exhibits great variations; some being dark-coloured and comparatively heavy, while others are lighter in colour and much less dense; in some cases the rock is compact, while in others it is spongy or cindery, when it is said to be **scoriaceous.** The little cavities or vesicles in this **scoria,**[1] or cellular lava, are formed by the disengagement of bubbles of gas or vapour, when the matter is in a pasty condition; just as the porous texture of a piece of bread is due to the presence of bubbles of gas evolved in the fermentation by yeast. The stone largely used for scouring paint under the name of **pumice,**[2] is a lava of very porous texture; its name recalling its origin as the froth or scum of lava. Sometimes the masses of lava, being tossed into the air, are rotated during their flight, and fall as more or less rounded bodies, known as **volcanic bombs.** Occasionally a very liquid lava may be caught by the wind, and drawn out into delicate fibres, like

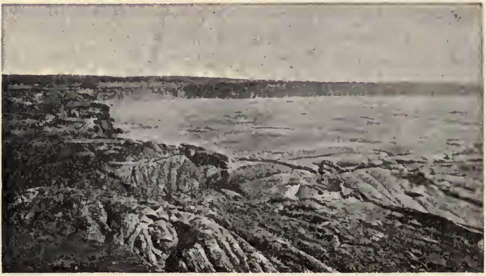

Photo. *G. W. Wilson.*

FIG. 170.—Crater of Kilauea, Hawaii. A lake of lava covering an area of about four square miles.

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[1] *Scoria*, volcanic cinder, from Lat. *scoria*, "dross."

[2] *Pumice*, from the Lat. *pumex*, formerly *spumex*, allied to *spuma*, "froth."

spun glass: this beautiful form is very abundant at Kilauea, a volcano in Hawaii, one of the Sandwich islands, where it is known as **Pélé's hair,** its name being borrowed from that of an old goddess who was supposed to reside in the crater. Other lavas again are vitreous, and strongly resemble dark-coloured bottle-glass, when they pass under the name of **obsidian.** This kind of lava was largely used by the ancient Mexicans for making rude knives and other cutting instruments; and a hill in northern Mexico, formerly worked for this material, is still known as the Cerro de Navajas.[1]

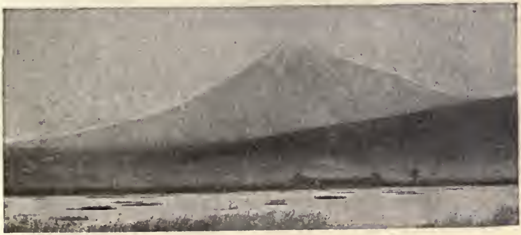

FIG. 171.—Fuji-san or Fusiyama, Japan. A dormant volcano. The last eruption occurred in 1707. From a photograph.

Volcanic cones.—A volcanic cone sometimes maintains its symmetrical form while attaining a great height. A remarkable instance of this is the beautiful volcano of Fuji-san in Japan, 12,000 feet in height (Fig. 171). But more often disturbing influences lead to rupture of the cone, and the addition of excrescences. For example, it often happens that the lava which wells up in the pipe of a volcano, breaks by its sheer weight through the rim of the crater, or even breaches one side of the conical hill. Fig. 172 represents a group of small extinct volcanoes in Central France, showing cones which have been broken through in this way. In some cases the flanks of the cones are rent, and lava is then injected into the cracks, forming, when cold, huge rocky ribs known as **dykes.** In other cases, the chimney gets choked by a plug of hard lava, and new vents may then be opened on the side of the cone. Fig. 162 is an ideal section of a volcano, showing the dykes of lava running through the stratified deposits, and also showing two minor cones, thrown up at points where the volcanic matter has been able to

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[1] Spanish, Hill of Knives.

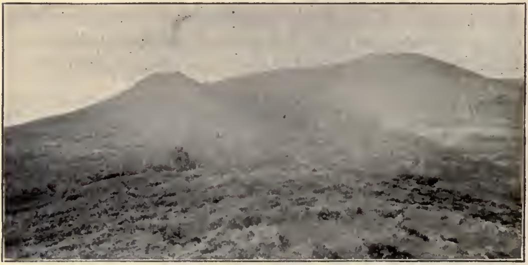

FIG. 172.—Breached cone of an extinct volcano, Puy de la Vache, Auvergne. From a photograph by Prof. H. J. Johnston-Lavis.

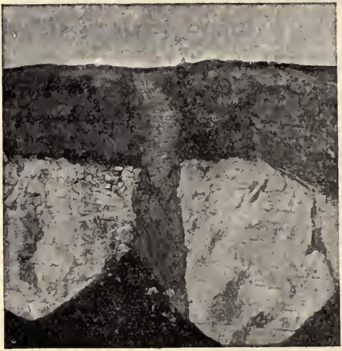

Photo. *R. Welch.*

FIG. 173.—Basalt dyke traversing chalk and basalt lavas, Cave Hill, Belfast.

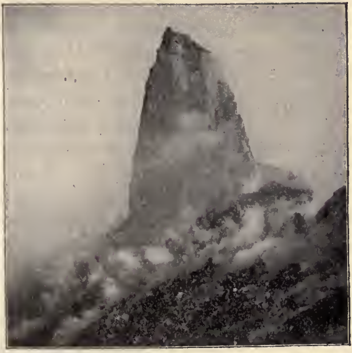

FIG. 174.—Lava plug rising from the summit of Mont Pélée. From a photograph taken from the rim of the crater on June 13, 1903, by Prof. A. Heilprin.

force its way to the surface. Mount Etna is remarkable for having its flanks studded with parasitic cones, some of which are of considerable size, one being upwards of 900 ft. in height.

After a volcano has long been silent and the large crater has been more or less filled, partly by ejected materials which had fallen back into the cavity during the last eruption, and partly by matter

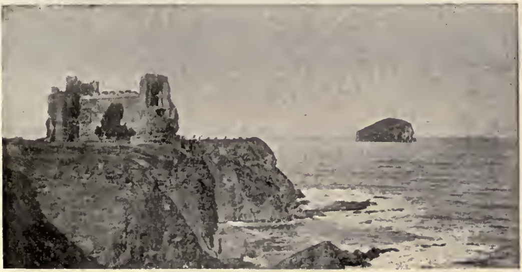

Photo. *Valentine and Sons.*

FIG. 175.—Tantallon Castle and the Bass Rock, Canty Bay, N.B. The isolated rock is the plug or neck of an ancient volcano, and marks the position of a vent formerly filled with molten rock.

washed in by rain, renewal of activity through the old channel may give rise to the formation of a new cone seated within the old crateral hollow. Great changes may indeed be effected in the character of a volcano by successive eruptions, new cones being thrown up at one time, and old ones obliterated at another. The curious stages through which a volcano may pass are well illustrated by the story of Vesuvius.

Vesuvius.—Rather less than two thousand years ago, that mountain was as peaceful as any hill in our own islands is at the present day. It seems from all accounts to have had a very regular conical shape, with a crater about a mile and a half broad. Yet its shape led hardly any one to suspect that the mountain was a slumbering volcano. Wild vines were growing over the sides of the crater; and it was in the natural fortress formed by this great amphitheatre that Spartacus the Thracian, with his little band of gladiators, took up his position at the beginning of the Servile War in the year 72 B.C. Earthquakes, as already pointed out, are often the heralds of volcanic eruptions; and the first notice which the old dwellers around Vesuvius received of its re-

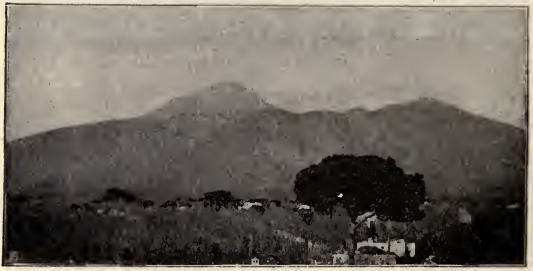

FIG. 176.—Monte Somma and Vesuvius. From a photograph by Prof. H. J. Johnston-Lavis.

newed activity was from a series of earthquakes which began, as far as we know, in A.D. 63, and continued intermittently for about sixteen years. These disturbances culminated in the great eruption of A.D. 79, which has been described in two letters written by Pliny the Younger to Tacitus. So vast were the quantities of ashes and other fragmentary matter ejected during this eruption, that the unfortunate cities of Herculaneum, Pompeii, and Stabiæ were buried beneath the deposits, in some places thirty feet in thickness. It is doubtful, however, whether any true lava was erupted on this occasion. From that date to the present day, Vesuvius has been more or less active, though sometimes quiet for considerable intervals. During the great eruption just referred to, the south-western side of the original cone was destroyed; but the half which was then left has remained in existence up to the present time, and forms the semicircular hill known as Monte Somma (Fig. 176).

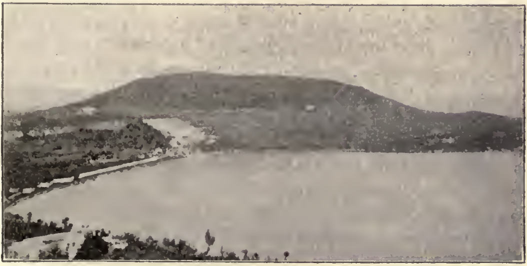

FIG. 177.—Monte Nuovo and the lake Avernus. The volcanic cone was formed in two days in 1538. The lake occupies an old crater. From a photograph by Prof. H. J. Johnston-Lavis.

An interesting case of a volcanic cone the formation of which was actually observed is provided by Monte Nuovo, near Naples (Fig. 177). In 1538, after a period of earthquake disturbances, a strip of land on the shore near Lake

Avernus was raised slightly above sea-level, and volcanic materials were ejected from a crack in the surface. The eruption only continued for a few days, but in that time the accumulation of volcanic dust and scoriæ built up a hill to a height of more than four hundred feet.

Submarine deposits and eruptions.—When a volcano is situated near the coast—and by far the larger number of existing volcanoes are so situated—the ashes may be showered into the sea, or be borne thither by the wind, and may in this way get mixed with the detrital matter which is spread over the sea-bottom. A curious series of deposits may thus be produced, consisting partly of materials worn away from the land by the action of the water, and partly of matter ejected from subterranean sources. In some cases, volcanic outbreaks take place actually beneath the sea, and the matter thrown up becomes mixed with the remains of shell-fish and other marine organisms. Submarine volcanoes occasionally give rise to new land, the erupted matter being piled up in sufficient quantity to form an island rising above the waters.

Underground temperatures.—In attempting to explain the origin of the intensely heated matter thrown out by volcanoes, we must consider certain phenomena of the temperature of the earth which have been observed experimentally. If a thermometer be buried in the ground at a depth of only a few inches below the surface, it is found to be affected by all superficial changes of temperature, and its indications show that it is cool at night and warm in the day, cold in the winter and hot in the summer. But plunged deep enough into the ground, or placed in a very deep cellar or cavern, these variations disappear, and a more uniform temperature is registered in all circumstances. What that temperature is will depend principally on the climate of the locality, the constant temperature being nearly the mean temperature of the surface.

On going still deeper, the heat is found to increase; and at the bottom of a deep mine it is generally so warm that the miners are glad to discard most of their clothing. The temperature at the bottom of Ashton Moss Colliery, Manchester, 2790 feet underground, is 85° F., and the average increase has been found to be 1° F. for 77 feet of descent. Somewhat different results have been obtained from observations made during the sinking of other pits, the rate of augmentation being affected by the character of the rocks bored through and by the position which the strata occupy; whether, for example, they are inclined or horizontal. Perhaps it will not be far wrong to assume that the average increase is 1° F. for every 64 feet: such at least is the rate which was adopted a few years ago by a committee of the British Association from a study of observations made in many mines, tunnels, and bore-holes.

Temperatures at great depths.—Even the deep mine or bore-hole is but the veriest dent in the earth's surface compared with the actual radius of the globe. It gives therefore but scant information respecting the temperature of the deep-seated portions of the interior; but, assuming such a rate of increase to continue, it is evident that at the depth of only a few miles the heat would be sufficient to fuse any known rock, that is, if there were no counteracting influence. However, it is known that under pressure most substances remain solid at temperatures above their ordinary melting point: and it is obvious that at great depths the pressure must be prodigious, and the resistance to melting correspondingly increased. Thus in all probability the materials generally remain solid.

Origin of volcanic force.—How then shall we account for the appearance of these materials in the liquid form in volcanic eruptions? The subject is so difficult of investigation that our knowledge of it is as yet very imperfect; but the following seems to be an approximate explanation. As already mentioned, in the folding of the earth's crust the rocks yield to lateral pressure by bursting upwards at the weak spots. By their upward movement they relieve the pressure which prevented the underlying intensely hot material from melting, and thus it rises in a molten form and fills the cavities and fissures. The crushing caused by lateral pressure must of itself raise the temperature and favour the local melting; and again, as the molten rock rises it gets into regions of less pressure, where its fluidity is retained though the temperature may be lower. In any case the intensely heated material, the normal situation of which is at a depth of several miles, is brought near to the surface, and only needs an expulsive force to cause its eruption in volcanic fashion.

It is evident that a great deal of the force by which volcanic products are brought to the surface and expelled is due to the expansion of intensely heated water into steam. There are two possible sources of this water: it may be a natural constituent of the deep rocks, existing in a state of mechanical mixture or solution in them, and retained only under great pressure; or it may obtain access to great depths by percolating through cracks leading from the sea and other superficial waters, and may become subsequently dissolved in the heated substance. As soon as pressure is relieved, the water escapes as steam, expanding and frothing the lava, and sometimes ejecting it; behaving, in fact, much like the carbon dioxide gas escaping from soda-water when the bottle is opened.

Another expulsive agent in volcanic action may be the lateral pressure of the crust, narrowing the cavities in which molten rock is confined. Here it may be said that we are obliged to regard the lava as confined in local cavities. If there were a general reservoir of fluid rock within the earth, with which all volcanoes communicated, it would be difficult to account for the escape of material from one safety-valve rather than another. There are even volcanoes quite near to each other which evidently communicate with separate cavities. For instance, in Hawaii (Sandwich Islands) there are two volcanoes, the level of the liquid lava in one of them standing 10,000 feet above that in the other: if they communicated with the same reservoir, the liquid would find the same level in both.

Fissure eruptions.—Mention must be made of a rarer form of eruption, which seems to result from stretching of the earth's crust. Such stretching has occasionally produced gaping rents of such a depth as to allow the intensely heated material to escape from below. The quantity of melted rock poured forth from such great fissures can be much greater than is possible from a mere chimney-like volcano, vast areas of land having been, so to speak, inundated with a sea of lava. The explanation given for ordinary volcanic eruptions will apply with modification to these latter phenomena. The material, though intensely heated, was kept in the solid state as long as it was under pressure of the overlying rocks: but on the occurrence of a rent the pressure was relieved, and the material became liquid. Since it must expand at the same time, it became lighter in specific gravity than the overlying rocks, and thus it tended to rise above them. No such lava inundation has occurred within the memory of man, so we have no knowledge of the phenomena accompanying it.

It is probable that the heated matter of the interior comes nearer to the surface as a rule in localities where the rocks are undergoing disturbance, and that this is one of the causes of discrepancy between the underground temperatures at different places.

Hot springs.—Evidence of the internal heat of the earth is furnished by the temperature of the water yielded by certain springs. Some of the hot springs at Bath, for example, have a temperature of 120° F. Still hotter springs occur in many countries; and, in volcanic districts, even the boiling point is occasionally reached. The water of these springs may acquire its heat by travelling either through rocks situated so deeply that their temperature is always high, or through superficial rocks heated by volcanic action. The most remarkable hot springs are those known in Iceland as **Geysers.** Jets of boiling water with clouds of steam are intermittently thrown high into the air with great force and accompanied with loud explosions. The water generally holds silica in solution, as mentioned on p. 133, and this siliceous matter is deposited around the mouth of the hole as an incrustation called **sinter.** Although the Geysers of Iceland are perhaps best known, similar springs are found in New Zealand, and also in the Rocky Mountains of North America, where, within the area of the Yellowstone Park, no fewer than 10,000 hot springs, geysers, and hot lakes are said to exist. The geyser represented in

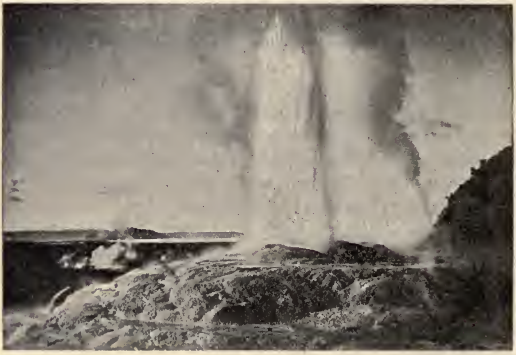

Photo. *Valentine and Sons.*

FIG. 178.—Waikité geyser, Whaka-rewa-rewa, New Zealand.

action in Fig. 179 throws jets of hot water to a height of something like 200 feet.

Mineral deposits around hot springs.—It was formerly supposed that the deposits of carbonate of lime, or **travertine,** formed where calcareous springs issue into the air are always produced by chemical action. Careful examination of the springs at Carlsbad and other European localities, and of the travertine deposits in the Yellowstone National Park, U.S.A.—where they cover an area of two square miles and in places have a thickness of 250 feet—have shown that certain simple plants play a most important part in their formation in many cases. Algæ of many colours flourish in the steaming waters of such springs as the Mammoth Hot Springs (Fig. 180), and their filaments serve not only as nuclei upon which travertine is deposited, but also extract the carbon dioxide from the water and so lead to the precipitation of the carbonate of lime held in solution. The large areas of siliceous sinter found around the geysers of the Yellowstone Park region have also been separated from the hot streams by the action of algæ, and

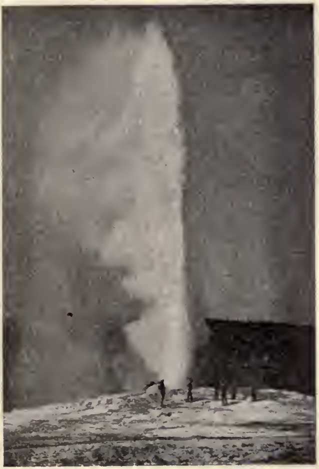

FIG. 179.—"Old Faithful" geyser in action, Yellowstone National Park, U.S.A.

are not deposits produced merely by the evaporation of geyser waters charged with silica.

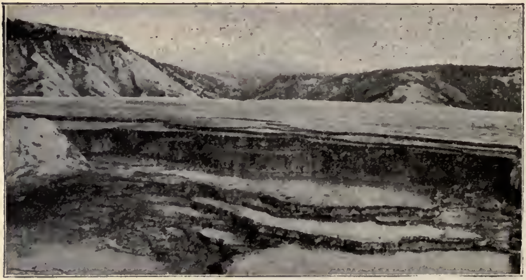

Photo. *Photochrome Co.*

FIG. 180.—Mammoth Hot Springs, Yellowstone National Park, U.S.A. The terraces are due to the deposit of carbonate of lime through the agency of certain simple plants—algæ.

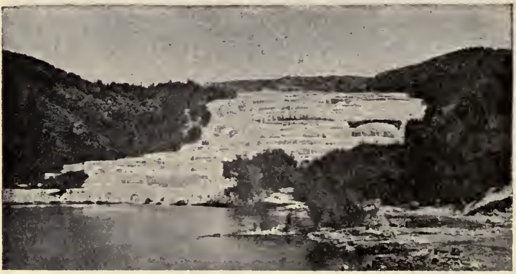

Photo. *Valentine and Sons.*

FIG. 181.—White Terrace, New Zealand, formed of siliceous sinter. The terraces were destroyed during a volcanic eruption in 1886.

Minor forms of eruption.—In some localities hot water issuing from the ground is mixed with earthy matter;

and streams of thick mud accumulate round the openings, so as to form conical hills, known as **salses** or **mud volcanoes** (Fig. 182). Such eruptions of mud, varying greatly in consistency and in temperature, occur in the Crimea and on the shores of the Caspian Sea. In other cases hot vapours issue from cracks in the ground, as at the Solfatara near Naples, where the vapours are charged with sulphur. A large industry has sprung up in the Tuscan Maremma, by utilising the hot vapours which issue from smoking cracks, and contain particles of boracic acid, which are used in the preparation of borax. These phenomena are probably to be regarded as representing the lingering remains of volcanic activity. When a volcano has become extinct, the effects of subterranean heat in the locality may still manifest themselves in a subdued form, in such phenomena as those of hot springs. Many volcanoes, however, which appear at the present day to be perfectly quiet, are merely dormant, and may

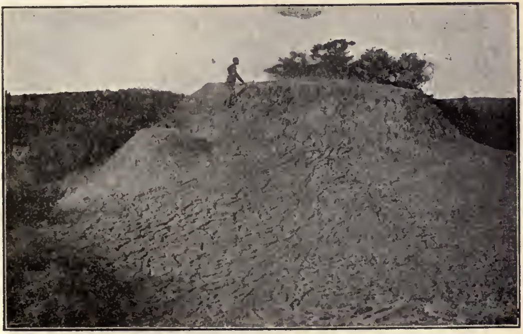

Photo. *Valentine and Sons.*

FIG. 182.—Mud volcano, Waiotapu Valley, New Zealand.

break forth with renewed activity at any moment. The early history of Vesuvius, as already pointed out, shows that a volcano, after being silent for ages, may suddenly start forth into fresh life.

Extinct volcanoes.—There are few better examples of an area in which volcanic action must have been rife on an enormous scale at a comparatively recent time, than that furnished by the Auvergne and the neighbouring districts in Central France. There the traveller may see hundreds of volcanic cones, known locally as "puys," still preserving their characteristic shape, in spite of long exposure; there, too, are the streams of lava just as they flowed from the craters, or burst through the sides of the cones (Figs 172, 183), whilst thick sheets of old lava and beds of ash are spread far and wide over the surrounding country. The district known as the Eifel, on the west bank of the Rhine, between Bonn and Andernach, offers equally striking examples of extinct volcanoes.

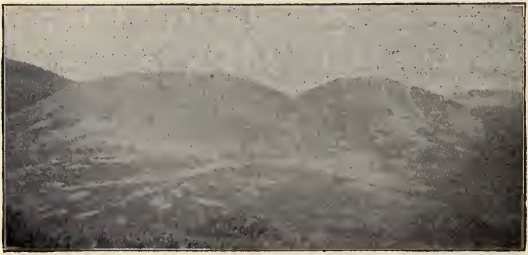

FIG. 183.—Extinct volcanoes: Puy de la Vache, and neighbouring cone, Auvergne. From a photograph by Prof. H. J. Johnston-Lavis.

Evidences of volcanic action in Britain.—Even in the British Isles, it is not difficult to trace the remains of ancient volcanic outbursts, although these are not so fresh and well marked as those just mentioned. Sheets of lava are found in the north-eastern part of Ireland, especially in the county of Antrim, where the remarkable scenery of the Giant's Causeway is due to the fact that some of the old lava, shrinking as it cooled, has split up into columns, not altogether unlike those into which a mass of starch splits during drying. Similar evidence of volcanic action may be found in Scotland, whilst in North Wales there are extensive remains of eruptive rocks; the state of fiery activity which they indicate dates back, however, to a very remote period of geological history. Yet it must not for a moment be supposed that any volcanic cone or crater exists amongst the volcanic hills of Wales. So great, indeed, has been the disturbance and denudation of this part of the earth, that the old surface has long ago been swept away, and its present shape bears little or no relation to its form

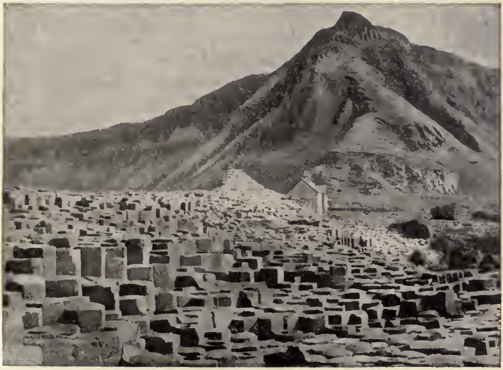

Photo. *R. Welch.*

FIG. 184.—The Giant's Causeway, co. Antrim, from the sea.

at the period of eruption. It is true, for example, that the summit of Snowdon is formed of volcanic rocks; yet the mountain, in its present form, does not in any way represent an old volcanic cone: it is rather a remnant of a lava bed, worn to its present form by denudation.

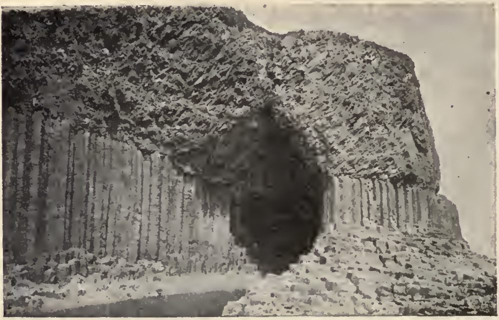

Photo. *Valentine and Sons.*

FIG. 185.—Columnar basalt, Fingal's Cave, Staffa.

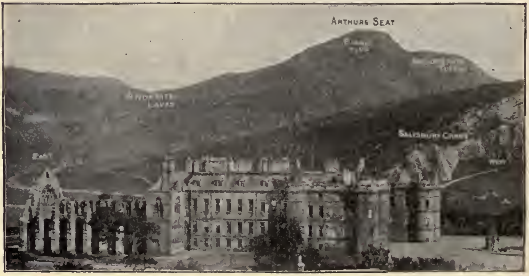

Photo. *G. W. Wilson.*

FIG. 186.—Arthur's Seat, Edinburgh. Relics of an ancient volcano.

Rise and decay of land.—From what has been said in this and the previous chapter, it will be seen that the earth movements tend constantly to add to the quantity of dry land: for among the many alternating movements there is a preponderance in the upward direction; and besides, fresh material is brought to the surface from volcanic sources. While the solid land is being continually washed down, little by little, into the sea, it is at the same time being replenished by the raising of new material. Since the greater part of this material consists of the very substances which were previously washed from the land and deposited on the floor of the sea, there is a continual circulation of solids, as well as of water, from the land to the sea, and from the sea again to the land.

CHAPTER XIII

STRUCTURE AND ACTIVITIES OF LIVING MATTER

Ultimate result of denudation.—It has been seen that the fresh and salt waters which run upon, and beat against, the land, are constantly engaged in transporting the materials of which that land is composed from higher to lower levels. A comparatively insignificant fraction of these materials remains in the lakes which lie in the course of some rivers; but by far the greater part, sooner or later, reaches the sea.

The solid deposits which thus accumulate on the sea-bottom are never exactly equal to the waste of the land, but are always of less, and frequently of much less, mass. For all the chief constituents of the land are more or less soluble in water; and hence, a larger or smaller proportion of the products of denudation reach the sea in a state of solution, and are diffused through the ocean, as the salt in a drop of brine would be diffused through a pail of water. Notably, dissolved **carbonate of lime** and **silica** are thus being constantly poured into the sea.

Supposing that no influences were at work upon the earth's crust except those of rain and rivers, and of the sea; then, as has been pointed out in Chap. X, the ultimate result of their action would be the reduction of the solid land to a submarine plain. The waters covering this plain would be more or less completely saturated with the soluble materials extracted from the denuded rocks. Denudation, therefore, on the whole, not only diminishes the quantity of dry land, but also lessens the proportion of the solid to the fluid constituents of the globe.

Compensating influences.—Denudation is compensated in some measure by the movements of the land, which tend on the whole to upheaval, and by volcanic action, which replenishes the surface with fresh material from the interior; and it is conceivable that the opposite processes should go on, for any assignable time, in such a manner that the proportion of land above the sea level to that below it should remain unchanged. But, in the operations of nature hitherto dealt with, there is nothing to compensate for the gradual conversion of solids into liquids by denudation; nor for such out-pouring of vapours and gases into the atmosphere as occasionally, if not always, accompanies volcanic action.

Nevertheless an agent, by which some of the gaseous and liquid constituents of the earth are temporarily or permanently reduced to the state of solids, is at work upon an enormous scale. This agent is what is termed **living matter**; or, **organic matter.**

Plant and animal life.—The surface of our country is covered with prodigious multitudes, and seemingly endless varieties, of the forms of this living matter, some of which we call plants, and others animals. But, notwithstanding their obvious differences, there are so many deep-seated points of agreement among the diversified forms of life that any plant or any animal will serve to illustrate the essential characters of all plants and of all animals. Every one has seen a field of peas, thronged with pigeons. The peas will serve very well as examples of plants, and the pigeons as types of animals.

However widely the pigeon and the pea-plant differ in external features, they nevertheless resemble each other (and all other living things) in their chemical composition, microscopic structure, and method of growth.

Subjected to chemical analysis, all plants yield a number of complex bodies. Among these the most important (though not most abundant) are certain compounds known as **proteids,**[1] which are composed of the elements nitrogen, oxygen, carbon, hydrogen, and sulphur: some proteids are combined with phosphorus also. Besides these, plants contain several compounds of the three elements carbon, hydrogen, and oxygen, among which are fat, sugar, much starch, and woody substance known as **cellulose.** The mineral substances present are various salts of potassium, sodium, calcium, and magnesium; also peculiar iron compounds.

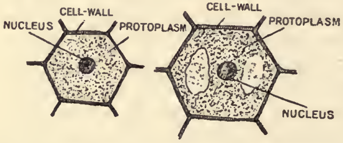

FIG. 187.—General structure of simple cells. Magnified.

Similarly analysed, the bodies of animals yield most of the above-mentioned substances, the exceptions being cellulose, which is absent, and starch, which is substituted by a nearly related substance, **glycogen.**

If thin sections of the pea-plant are examined with a microscope, it will be seen that their substance consists of a delicate framework or skeleton of cellulose, in which there are innumerable tiny cavities; and that each cavity is filled with a semi-fluid matter, termed **protoplasm,**[2] just as the waxen cells of a honeycomb are filled with honey (Figs. 187, 188). Embedded in each little mass of protoplasm is a rounded body called a **nucleus**; and the protoplasm, with its nucleus and its investing **wall**, is technically termed a **cell**. The nuclei are complex in structure and formed largely of phosphorus compounds. The protoplasm is scarcely less complex, and is made up of water, salts, sugar, and various proteids, holding in suspension minute drops of fat and granules of starch. The cell walls consist mainly of cellulose. The cells, though varying in size, are always minute, a diameter of about $\frac{1}{1000}$th of an inch being not unusual.

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[1] *Proteid,* from *πρωτεύω, proteuo,* to have the first place.

[2] *Protoplasm,* from *πρῶτος, protos,* first; and *πλάσμα, plasma,* formative matter.

In the various organs of the pigeon we find cells which correspond in their general features with those in the plant. They are formed of nucleus, protoplasm, and a more or less distinct investing wall, but no granules of starch are present in the protoplasm; and whereas in the plant the cell-walls of cellulose give firmness to the structure, cellulose is absent from the animal, and the cells are generally supported by fibrous material deposited between them (Fig. 188).

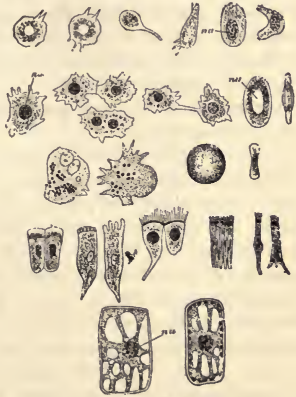

FIG. 188.—Typical animal and vegetable cells, as seen under the microscope. (Parker.) *nu*, nucleus. The two bottom figures represent plant cells, the left-hand one being a cell from the root of a lily, and the right-hand one from the leaf of a bean.

In both animals and plants, growth occurs by the repeated subdivision of cells, each new cell appropriating nutriment from its surroundings until it becomes as large as that from which it proceeded. By means of such subdivisions repeated indefinitely, with various modifications of form and function of the cells, the whole plant or whole animal grows from a single embryo cell. It should be remembered, however, that the seed of the pea, or the egg of the pigeon, does not contain a mere embryo cell; for in the new-laid egg the cell-division is already well started, and in the ripe pea it is so far advanced that the first leaves of the embryo plant, together with a minute stem and rootlet, are already discernible.

Growth from without and within.—There is a very striking difference between the growth of such not-living bodies as may be said to grow, and living growth. A crystal can grow only if the materials of which it is composed exist, as such, in the liquid which surrounds it. A crystal of salt can grow only in a solution of salt; a crystal of sulphate of soda, in a solution of sulphate of soda: and when a crystal grows, the new matter is added only upon its exterior.

It is quite otherwise with a plant. A single pea may not only develop into a large pea-plant, but may ultimately give rise to a multitude of peas as large as itself. In other words, the pea, in the course of its development, accumulates within itself many thousand times the quantity of proteids, of cellulose, of starch, of sugar, of fat, and of water and mineral salts, which it primitively contained. Nevertheless, of all these bodies, it is certain that none but the water and the mineral salts exist, as such, either in the air or in the soil. In fact, strange as it may seem, the soil is a superfluity. A pea will grow into a perfect plant, and produce its crop of peas, if it is supplied merely with water containing nitrate of ammonia and the phosphates, sulphates, and chlorides of potassium, calcium, iron, and the like, which it needs, and if it is freely exposed to the air and to sunshine. Under such conditions as these, it is obvious that the full-grown plant must be almost entirely composed of fluids and gases which have been transmuted into solid matters; and that it has manufactured the multifarious and often highly complex chemical compounds, of which its body is composed, out of the comparatively simple raw materials supplied to it.

Chemical conversions caused by plants.—In the case supposed, the fluid with which the pea is supplied contains only hydrogen, oxygen, nitrogen, phosphorus, sulphur, and certain metallic bases; but another element, carbon, enters largely into every one of the manufactured articles which are to be found in the full-grown plant. The presence of this carbon, and its great relative amount, may be made manifest enough if the plant is strongly heated in a closed vessel, when the carbon remains as a conspicuous mass of charcoal. Whence is this carbon derived? Under the conditions defined, the only possible source of supply is the carbon dioxide diffused through the atmosphere; which, though it forms so small a percentage of the air, yet amounts to an enormous absolute quantity (p. 83). In fact, it is known that under the influence of sunlight a green plant absorbs carbon dioxide from the atmosphere and decomposes it; returning a part of its oxygen to the air, and building up the carbon and the rest of the oxygen, together with nitrogen, hydrogen, sulphur, and mineral matters derived from other sources, into the complex compounds of its own living substance. It should be noted that the plant decomposes the oxides of all the elements here mentioned as well as that of carbon.

Thus the green plant transmutes the fluid and gaseous matters, which it draws from the soil and from the atmosphere, into the solid materials of its own body; and thus, to a certain extent, reclaims the solids lost by the aqueous solution and igneous decomposition which have been considered in previous chapters. In ordinary circumstances, the restoration of solid matter to the earth, thus effected by plant-life, is only temporary. Even during life, the activity of the green plant, like all vital activity, is accompanied by the slow oxidation and destruction of its protoplasmic matter; and one of the products of this oxidation, carbon dioxide, is returned to the atmosphere. After death, the process of decay is accompanied by slow oxidation. The carbon goes off chiefly as carbon dioxide; the nitrogen in the shape of ammoniacal salts; and the mineral salts are dissolved away by rain and carried to the general store of the waters. But if by the overflow of a river the plant should become silted up in mud, or carried away by floods and buried in the sea-bottom, the process of decay may be so slow and so imperfect that its carbonised remains, often infiltrated with mineral matter, may be preserved as a **fossil**,[1] when the mud is hardened into a stone, and may thus permanently contribute to the solid land.

Plants and animals compared.—Though there are close analogies between the animal and the vegetable forms of life at present under consideration, there is nevertheless one striking difference. A pigeon cannot live on a watery solution of ammoniacal and mineral salts, however much fresh air and sunshine may be added to this diet. It has not the faculty of building its tissues out of such raw materials as ammonium nitrate, carbon dioxide, and water; but requires that the nitrogen, carbon, and hydrogen compounds shall be partially worked up for it by plants. It is evident that animals derive nearly all their food, directly or indirectly, from plants; the only exceptions being water and a part of the saline food.

The plant performs on the average more deoxidation than oxidation; delivering oxygen to the air, and storing up combustible substances in itself. The animal, on the contrary, is concerned chiefly with oxidation ; and takes oxygen from the air, to use it in burning the materials which were previously deoxidised by plants.

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[1] *Fossil*, Lat. *fossilis*, from *fodio*, to dig; a term applied by old writers to anything dug out of the earth, and therefore including minerals, but now conventionally restricted to organic remains.

Putrefaction.—It may here be noted that putrefaction, the final stage of destruction of both animal and vegetable matter, is effected by lowly organisms or **microbes** of various kinds, amongst which the **bacteria** are the most important. These are very minute beings, related by their structure to the lowest members of the vegetable kingdom, but resembling the animals in requiring that their food shall have been previously constructed by other living things.

Change and decay in animal life.—The complex substances which the pigeon obtains from the peas on which it feeds are assimilated to its own substance, and are then slowly burned by the oxygen which it obtains by the process of respiration. The animal is in fact a machine, fed by the materials it derives from the vegetable world, as a steam-engine is fed with fuel. Like the steam-engine, it derives its motor power from combustion ; and, as in the case of the steam-engine, the products of the combustion are incessantly removed from the machine. The smoke and ashes of the animal are the carbon dioxide and water evolved in expiration, and the fæcal and urinary excreta. The latter are returned to the earth in a more or less fluid, or, at any rate, soluble form ; the former are diffused through the air.

When the bird dies, the soft parts rapidly putrefy, and pass off, as gaseous and fluid products, into the air and the water. The dense bones resist decay longer ; but, sooner or later, even the lime salts by which they are hardened are dissolved away ; and the solid animal fabric returns to swell the sum of the fluids and gases from which, through the plant, it has been derived. But, under like conditions to those which have been mentioned in the case of the plant, the bones may be covered up and protected from further decay, or may become infiltrated with calcareous or siliceous matters; and thus, as a fossil bird, a pigeon may form an integral part of the solid crust of the earth.

Natural constructors and consumers.—It will be apparent that pigeons and peas, or more broadly, the animal and the plant, respectively represent, in the world of life, the destructive and the reparative powers of the not-living world—the forces of denudation and of upheaval. The animal destroys living matter and the products of its activity, and gives back to the earth the elements of which such matter is composed, in the form of carbon dioxide, water, and ammoniacal and mineral salts. The plant, on the contrary, builds up living matter, and raises the lifeless into the world of life. There is a continual circulation of the matter of the surface of the globe from lifelessness to life, and from life back again to lifelessness.

If pigeons and peas were the only forms of life, the balance of solid and fluid constituents of the globe would hardly be affected by their existence. Every pigeon and every pea, as has been seen, represents a certain amount of liquid and gas transmuted into the solid form; but, under ordinary conditions, the solids thus withdrawn return to the fluid and gaseous states within a short time after the death of the body which they constitute.

Fossils.—It is hardly conceivable that, in any circumstances, fossil pigeons or fossil peas should make a sensible addition to what may, at any rate in a relative sense, be termed the permanent crust of the earth. But it is otherwise with plants and animals which live under conditions more favourable for preservation; and in which the earthy and less perishable constituents enter in large proportion into the composition of the body. There is much more likelihood that the remains of animals and plants which live in the sea, or in rivers, or which haunt marshes and lakes, should be fossilised, than that those of the dwellers on dry land should be so preserved. The greater the quantity of silica, or of salts of lime, or of other slowly soluble ingredients, in the body of an animal or of a plant, the longer will its fabric be in disappearing, and the greater the chances of its preservation. It must be borne in mind, however, that such fossils form only an insignificant portion of the bulk of the rocks in which they are embedded, though, as will be shown in subsequent chapters, there are other organisms which enter so largely into the composition of certain deposits as to form by far the greater proportion of their bulk.

CHAPTER XIV

DEPOSITS FORMED BY THE REMAINS OF PLANTS

Solidified silica from plants.—There is a well known substance, which has been used in the arts for many years as a polishing material, under the name of **Tripoli powder,** or more accurately as **Diatom earth** or **Infusorial earth.** It is a kind of rottenstone, which occurs in large deposits in many parts of the world, but is especially abundant at Bilin, in Bohemia, and near Richmond, Virginia, where it forms a bed thirty feet thick and 100 square miles in extent (Fig. 189). In some places, the substance is a soft friable rock, while in other localities it is so hard as to be known as "polishing slate." Chemically it is almost pure silica, like the silica of rock-crystal; but examination under a microscope shows at once that it is not simply mineral silica. Indeed, when a little of this earthy material is sufficiently magnified, it is seen to be made up, not of shapeless mineral particles, nor of minute crystals of silica, but of such beautifully formed objects as those represented in Fig. 190. It was shown many years ago that these delicate objects are identical with the siliceous cases characteristic of a group of minute organisms called **Diatoms.** The diatoms are found living both in salt and in fresh water; but the kinds commonly preserved in infusorial earth are characteristic of fresh water. and hence it is concluded that the material was probably deposited at the bottom of lakes or in marshes.

When a living diatom is examined, it is seen that the siliceous case, which consists of two symmetrical halves, encloses protoplasm with a nucleus. A diatom is in fact a simple vegetable cell, but its peculiarity lies in the fact that the cell is able to separate, or *secrete*, from the surrounding water, that chemical combination which is called **silica,** which exists in minute proportion dissolved in most natural waters. With the silica thus appropriated the diatom forms a solid case, which encloses the protoplasm, and often exhibits a beautifully sculptured surface.

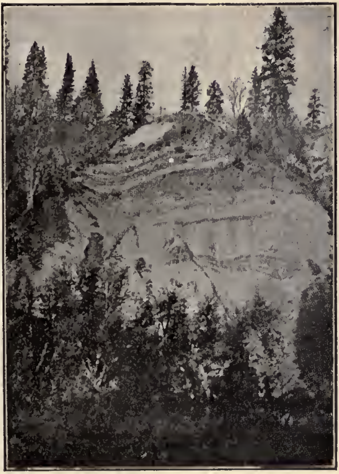

FIG. 189.—Deposit of diatom earth in Shasta County, California. Photographed by Mr. J. S. Diller. From *Bulletin* No. 150 of the U.S. Geological Survey.

On the death of a diatom, the protoplasm decomposes and disappears ; but the siliceous shield, although it is very slowly dissolved by water, is not easily perishable, and it therefore remains as a solid body at the bottom of the water.

Abundance of diatoms.—It is true the diatoms are very minute, but they compensate for this by their extraordinary abundance. Enormous multitudes of diatoms have been found in the waters and in the ice of the South Polar Ocean; and a deposit, or **ooze**, consisting principally of their siliceous casings, occurs along the flanks of the Victoria Barrier Reef, off the coast of Australia, extending over an area which measures as much as 400 miles in length and 200 in breadth. During the voyage of the *Challenger* a similar diatomaceous ooze was found, as a pale straw-coloured deposit, in certain parts of the Southern Ocean; and diatoms are seen in abundance on the surface of many seas, especially where fresh water is brought down by rivers. Insignificant as diatoms appear when regarded individually, it is clear that, in consequence of their vast numbers, the rapidity of their multiplication, and the resistance of their siliceous cases to destruction, they may

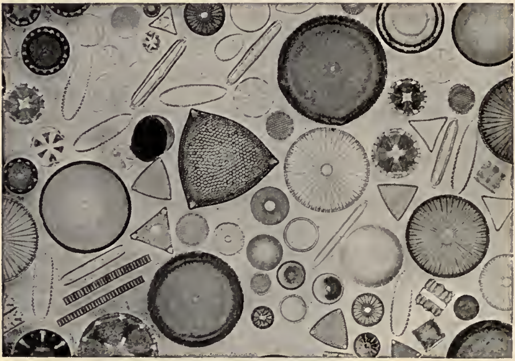

FIG. 190.—Groups of diatoms of various forms. Magnified 40 diameters. From a photomicrograph by Mr. J. E. Barnard.

play a very important part in the formation of certain deposits which will eventually constitute siliceous rocks.

Nature and formation of peat.—Accumulations of partially decomposed vegetable matter form the substance known as **peat** or **turf**. This is produced only under certain conditions of moisture and temperature; damp ground, in a temperate climate, being the situation most favourable to its formation. In this part of the world, the principal peat-forming plants are certain mosses known to botanists under the generic name of **Sphagnum.** The stems of the bog-moss die away in their lower part, while the upper portion continues to grow freely. The interwoven dead portions form a tangled mass, which holds water like a sponge and favours the growth of the moss above. Remains of other plants become mixed with the mosses, and contribute to the formation of the peat, while trunks of trees occasionally get embedded in the bog. Muddy matter is likewise washed in during floods, and helps to consolidate the felted mass and to produce a deposit of considerable firmness. The rate at which the peat grows varies greatly under different conditions; but some notion of the rate may be gained from the fact that Roman remains, and even Roman roads, have been found beneath eight feet of peat. In Ireland peat-bogs are so abundant as to cover about one-tenth of the entire surface of the country; and in some cases the peat may be as much as forty feet in thickness. The peat is cut from the bog, in brick-shaped blocks, by means of a peculiar spade known as a "slade," and, after being dried in stacks, is used as fuel. In England peat is not so important as in Ireland, but it is to be found in many damp localities.

Peat and coal.—In the deeper, and therefore older, parts of a thick peat-bog, where the decomposing matter is most compressed and altered, it usually takes the form of a brownish-black, slightly compact mass, in which the vegetable structure may be almost obliterated : the material is in fact converted into a substance not altogether unlike **coal.** Indeed, the resemblance has led to the suggestion that beds of coal may in some cases have been formed by the alteration of old peat-bogs. Although there are certain objections to such a view, it is nevertheless beyond question that coal owes its origin to the alteration of vegetable matter. The evidence, upon which this conclusion is founded, is derived partly from the chemical and microscopic structure of the coal, and partly from the conditions under which the substance is found in nature.

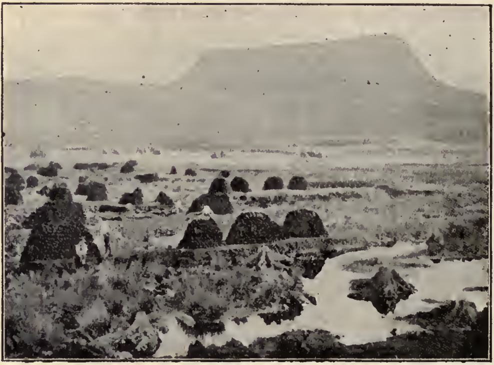

Photo. *R. Welch.*

FIG. 191.—Peat bog, Grange, Sligo. Roots of trees can be seen in the bog.

Character of coal measures.—Coal occurs in the shape of beds, or **seams,** of variable thickness, associated with shales, sandstones, and other sedimentary rocks. The succession of strata, or **measures,** cut through in a colliery is generally similar to that represented in Fig. 192, but the series may include hundreds of separate beds. The "roof" of the coal, or the rock immediately above the seam, is commonly a **shale,** which when split into layers is very frequently found to inclose impressions of plants. Perhaps the commonest of these remains are the graceful leaves or **fronds**[1] of ferns, which are often strikingly similar to those living at the present day. Although in these islands ferns never attain to the size of trees, yet in countries where the climate is very warm and moist, as in New Zealand, they form trees fifty or sixty feet in height. Such tree-ferns lived also in this country, at the time of the formation of the shales which are found in association with the coal. Part of an ancient coal-measure forest which extends for a large area around Glasgow, and is occasionally exposed by quarrying operations, is illustrated in Fig. 193. The trunks of the trees are rooted in dark shales and covered with sandy shales and sandstones.

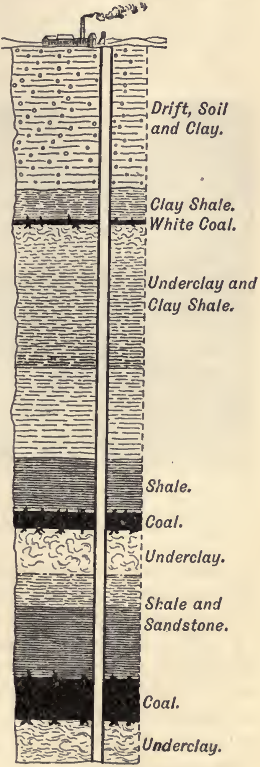

FIG. 192.—Section of coal measures.

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[1] A *frond* differs from an ordinary leaf in usually bearing reproductive cells or *spores*.

Tree stems and roots in coal measures.—In addition to the impressions of plants found in the shales above the coal seams, vegetable remains are thus met with in rocks beneath the coal, forming what is called the "floor." It was pointed out many years ago that each bed of coal in this country is supported by a layer of rock known as **underclay** or **seat-earth**, as shown in Fig. 192. Whatever the number of seams of coal—and in some cases they are very numerous—there is always just the same number of underclays. Moreover these underclays usually contain such bodies as that figured in Fig. 194, which are never found in the roof of the coal. Such objects had long been known to geologists under the name of **stigmariæ**,[1] but though it

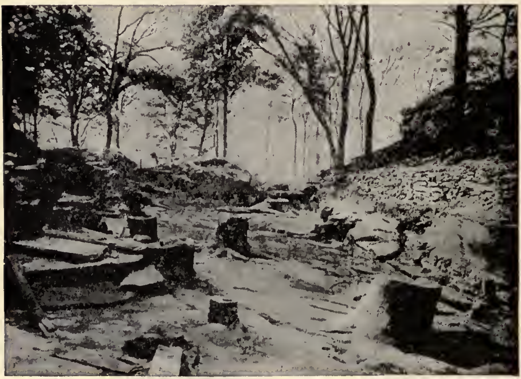

FIG. 193.—Remains of a coal measure forest at Victoria Park, near Partick, Glasgow. Photographed by Mr. J. R. Stewart, and reproduced by kind permission of Prof. W. W. Watts, F.R.S., secretary of the Geological Photographs Committee of the British Association.

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[1] *Stigmaria*, from *στίγμα*, *stigma*, "a mark"; in allusion to the scars left by the rootlets.

was clear they represented some part of a plant, their precise nature long remained an enigma. At length a railway cutting through the Lancashire coal-field exposed half a dozen trees resting upon a seam of coal, but sending their strong roots downwards into the underclay, where they ramified in all directions and gave off rootlets. It was found that these roots were nothing but the well-known **stigmariæ**, and that the characteristic stigmata, or pits, were not leaf-scars, as had been suggested, but points from which rootlets had been given off (Fig. 194). The stigmariæ passed upwards into fluted tree-stems, which are not uncommonly found in the coal and the shales, and are known as **sigillariæ**.[1] It is therefore evident that the stigmaria is nothing but the root of the sigillaria and allied trees, and that the underclay represents the soil of an ancient forest in which these and other trees flourished (Fig. 193).

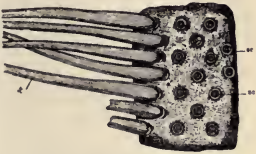

FIG. 194.—*Stigmaria ficoides.* Part of surface, showing the rootlet scars (*sc*), to some of which the rootlets (*rt*) are still attached. Much reduced in size. Reproduced by kind permission from Dr. D. H. Scott's *Studies in Fossil Botany* (Black).

In examining one of these sigillaria-stems, it will probably be found that the bulk of the trunk consists of stony matter, but that this is coated by a thin layer of coal which represents the original bark of the tree. It seems that while the surrounding softer and more fragmentary vegetable matter was rotting, and thus gradually changing into coal, the solid trunk was able to resist decay for a long time, long enough to allow the percolating water to deposit lime, &c., in the interstices of the wood, or, as we usually say, to petrify it.

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[1] *Sigillaria*, from Lat. *sigillum*, a seal; the leaf scars resembling the impressions of a seal.

Structure of a piece of coal.—On attempting to break a mass of coal, it will generally be found that it splits much more readily in certain directions than in others. Thus, it breaks easily along the planes of bedding, which of course run parallel to the general stratification of the coal-measures. The top and bottom layers thus broken, commonly present dull black almost sooty surfaces, and easily soil the fingers when handled. But the mass of coal also splits with ease in certain directions which run vertically across the stratification, and the broken surfaces thus produced are generally bright and smooth, and do not soil the fingers: the direction along which these joints run is often known as the "face" of the coal. Then there is a third set of planes, at right angles to both the other sets, and less perfect, so that the fracture here is more irregular; this direction is sometimes called the "end" of the coal. On the whole, then, there are three directions, perpendicular to one another, in which the coal may be divided; and it thus yields blocks more or less regular in shape, and roughly resembling cubes or dies, such as that shown in Fig. 195.

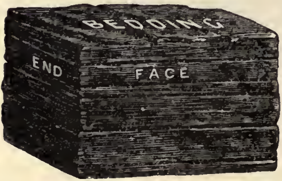

FIG. 195.—Cuboidal block of coal split along natural planes.

The dull black substance running along the planes of stratification or bedding of a piece of coal is sometimes called, from its resemblance to charcoal, **mineral charcoal**, and it is likewise known as **mother of coal**. This substance is often fibrous, and is made up to a large extent of the remains of stems and leaves. But the constitution of the mass of the coal is very different from that of the mineral charcoal, which indeed forms only thin layers spread out between the laminæ of the coal.

Microscopic characters.—If a slice of coal, cut so thin as to be partially transparent, is examined under the microscope by light passing through its substance, it will usually present some such appearance as those shown in Fig. 196. These sections, which were taken respectively across the bedding and parallel to it, show a blackish or dark brown mass forming the ground, in which are embedded characteristic bodies of a yellowish colour. These bodies are sections of the little cases which enclosed the **spores**[1] or reproductive cells of a flowerless plant. These spore-cases or **sporangia** are sometimes as much as $\frac{1}{20}$th of an inch in diameter, and therefore large enough to be seen with the naked eye. They sometimes contain a remnant of the spores,--tiny granules not more perhaps than $\frac{1}{700}$th of an inch in diameter, while great numbers of these are scattered

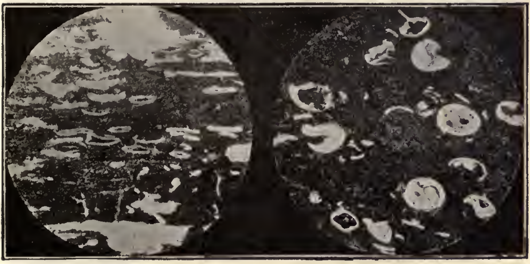

FIG. 196.—Photomicrographs of sections of coal across the bedding and parallel to it. From sections kindly lent by Mr. E. T. Newton, F.R.S., and photographed by Mr. J. E. Barnard. Magnified.

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[1] *Spores* are one of the kinds of bodies by which flowerless plants are reproduced. (See footnote, p. 275.)

through the dark ground-mass. Similar bodies are well seen in microscopic sections of the curious combustible substance known as "white coal" which is in course of formation in Australia.

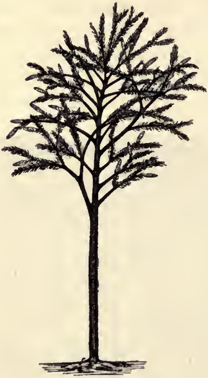

FIG. 197.—*Lepidodendron elegans.* Restoration of tree, bearing cones. The trunks of these trees were sometimes 100 feet long. Reproduced by kind permission from Dr. D. H. Scott's *Studies in Fossil Botany* (Black).

There can be no doubt that these spores and spore-cases were shed by trees closely related to those extinct forms which are well known under the name of **Lepidodendron**[1] (Fig. 197). Remains of the lepidodendron have been found, with cones still pendent from the branches of the tree; and similar cones, called **Lepidostrobi** (Fig. 198), are scattered in abundance through the coal-bearing rocks. The cones are made up of scales, and in some specimens it is possible to detect spore-cases, containing spores, still preserved between the scales. There seems therefore scarcely any room for doubt that the little bodies so plentifully scattered through most coals were derived from plants more or less resembling the lepidodendron.

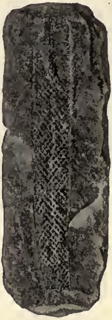

FIG. 198.—A Lepidostrobus, or cone of a Lepidodendron, found in the coal measures. One-third actual size. Reproduced from the Palæontographical Society's Monographs, 1868–1871.

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[1] *Lepidodendron*, from **λέπις**, *lepis*, a scale; **δένδρον**, *dendron*, a tree; in allusion to the scale-like leaf-scars on the stems.

Coal-forming plants.—But what kind of trees were these ancient inhabitants of the coal-forests, and to what existing plants could they claim kinship? To answer this question it is necessary to turn not to our forest trees, but to such lowly plants as the club-moss or **Lycopodium.** It may seem almost absurd to compare such different objects as these; for the club-moss is a weak herb, and even in the most favourable conditions does not rise to a height of more than two or three feet, while the lepidodendron must have been a gigantic tree, certainly reaching, in some cases, to a height of a hundred feet. Yet, in the form of their stems, and in the character of their fructification, the resemblance between the two is so striking, that the student is forced to admit that the club-moss is but a miniature edition of the old lepidodendron. But, though the ancient and the modern plants thus differ so much in size, it is curious to note that their spores are of nearly the same dimensions.

At first sight, it no doubt seems surprising that objects so minute as the spores and spore-cases of extinct plants allied to the club-moss should form any considerable proportion of those vast masses of coal which occur in beds several feet in thickness, and extend over areas measured in miles. Yet in this case, as in that of the diatoms, the enormous numbers compensate for want of size in the individuals. Clouds of yellow dust, consisting of spores, may be shaken from a branch of club-moss; and the spores of the diminutive species still living are so abundant that they form an article of commerce. The druggist rolls his pills in lycopodium spores, and, by thus coating them with a resinous powder, enables them to roll over the tongue without direct contact with its moist surface. And, before the days of the electric light, the stage-manager was in the habit of using this highly combustible resinous material, under the name of "vegetable brimstone," to produce a blaze of mimic lightning.

Forest origin of coal. – From what has now been said, it appears probable that most coal has been formed in something like the following way. A forest of lepidodendrons, sigillarias, ferns, and other plants, grew up on an old swampy land-surface, which is now represented by the underclay, or its equivalent. Season after season, showers of spores fell from these flowerless plants, and, accumulating on the soil, became mixed with the fallen fronds, and with larger or smaller portions of the stems of the surrounding trees. While a large proportion of the soft vegetable matter slowly disappeared by decay, or left only a highly carbonized residue, of which the part that retains a recognizable structure is the "mother of coal," the resinous spores resisted decomposition, and remain distinguishable in all the less altered coals. The roots of the Lepidodendra were often preserved by the clay in which they grew, and became the fossil stigmariæ.

When a layer of vegetable soil had thus accumulated to a considerable thickness, the land slowly subsided, and the old swamp was buried beneath deposits of mud and sand, which have since hardened into shales and sandstones. Compressed beneath these sediments, the vegetable matter underwent peculiar changes, which resulted in the formation of coal. Then a time came when the sedimentary deposits were upraised, and another forest sprang up on the new land, forming a second bed of coal. Hence every seam of coal indicates fresh movement of the ground; and when it is remembered that, in the South Wales coal-field, as many as eighty distinct beds of coal may be recognized, it will be seen that the coal-measures offer striking evidence of oscillations of the level of the land. Between each elevation and depression, there must have been time enough for the formation of a thick vegetable soil, and in some cases this must have taken vast periods of time; thus, in South Staffordshire there is, or rather was, a famous bed of coal measuring as much as *thirty feet* in thickness. Remembering, then, the slow growth of a forest, the great thickness of some of our coal seams, and the number of separate beds in the coal-measures, it will be readily conceded that these strata represent a lapse of time which is probably to be counted by hundreds of thousands of years.

Drift theory of coal formation.—It is held by some geologists that coal has not been formed in the manner already described, but by the alteration of plant remains drifted out to sea or other expanses of water. Great masses of wood and other accumulations of vegetable matter are unquestionably carried down by such a river as the Mississippi; and this matter, becoming buried in the silt of the estuary, might undergo changes resulting in the formation of coal. According to the drift theory of the origin of a coal seam, sand and gravel with drifted plant remains were first spread over an area by the action of water. As the currents lost velocity, shale was deposited; and then there was a growth of presumably aquatic vegetation in extremely shallow water into which wind-borne vegetable dust and floating vegetable matter were carried. The area then subsided, with the result that a new system of sand and mud-laden currents was set up and the whole process was recommenced. But though small deposits of coal may have been formed in this way, it is generally held that no accumulation of drift material would be competent to produce beds of pure coal of uniform thickness and great extension, such as those found in most coal-fields. The balance of opinion is in favour of the growth-in-place theory which regards a coal seam as vegetation buried in the swamp where it originally flourished.

Brown coal.—There is a kind of imperfect coal which shows by its texture that it has been formed from wood. So ligneous indeed is its texture that the coal is commonly called **lignite.** In this country, such coal is found only in insignificant quantity at Bovey Tracey in Devonshire, but in many countries, which are poor in true coal, the lignite occurs in large deposits and is an important fuel. Several years ago, some old timbering in a mine in the Hartz, Germany, known to date back about four hundred years, was found to be converted into this lignite or "brown coal." Hence, there can be no doubt that, under certain conditions of decay, wood may be transformed into a coal-like material.

From vegetable matter to anthracite.—Lignite may be regarded as vegetable matter not completely mineralized. If it remained for ages deeply buried in the earth, and subjected to heat and great pressure, it might undergo successive alterations until it became true coal. And indeed the changes might not cease at that stage: even the ordinary coal of our own country is subject to further alteration, and may become still more removed in characters from its original condition. Thus, in the coal-field of South Wales, a curious change may be traced in passing from one end of the field to the other. In the eastern part, the coal is of the ordinary kind, such as is seen in our scuttles, and is called **bituminous** coal; towards the middle of the field this passes into **semi-bituminous** coal, which is a kind of fuel that does not burn with a bright gassy flame, but is valued for feeding the engines of steamers, since it emits but little smoke; finally, in the western part of the coal-field, this steam-coal passes into a substance called **anthracite,**[1] which is still less inflammable and still more removed from the original form of vegetable matter. Such changes in the character of the coal appear to be closely connected with the disturbance and fracture of the coal seams. Most deposits of coal have been thrown into basin-like shapes, and the beds are often broken up and otherwise disturbed by the injection of igneous rocks and

[1] *Anthracite*, from ἄνθραξ, *anthrax*, coal or charcoal.

by lateral pressure. In these disturbed regions, the coal has been altered into an anthracitic material. The alteration which has been effected appears to be much like that which takes place when coal is artificially distilled for the manufacture of ordinary illuminating gas. That part of the coal which contributes to the blaze of a fire is driven off as gas, while the coke-like portion is left behind.

Chemical analyses show that during the conversion of vegetable matter into coals of various degrees of hardness, the percentage of carbon increases and there is steady diminution of the gaseous constituents. For instance, wood consists of about fifty per cent. of carbon and fifty per cent. of hydrogen, oxygen, and nitrogen, but anthracite contains as much as 94 per cent. of carbon, and only six per cent. of gaseous constituents.

Changes of the kind indicated by these analyses have been carried on, during the past history of the earth, on an enormous scale; and the great extent and thickness of the deposits of coal, which have thus been produced, show that vegetable life has played no insignificant part in the formation of the rock-masses which build up the earth's crust.

CHAPTER XV

CORAL AND CORAL LAND

Shell and coral beds.—It has already been pointed out that when an aquatic animal dies, its hard parts, such as a shell, or bones, if it happen to possess any, will stand a fair chance of constituting a permanent contribution to the solid materials of the earth, by becoming embedded in mud, and preserved in this way from destruction.

Such names as "Shell-haven," near Tilbury on the Essex coast, and "Shell-ness," in the Isle of Sheppey, sufficiently indicate the abundance of shells which accumulate in certain regions of the estuary of the Thames; and on many other parts of the English coast enormous multitudes of shells are scattered upon the sea-beach and embedded in its sands and mud.

Vast quantities of dead shells accumulate on oyster-beds; and the dredge brings up similar objects, wherever it is allowed to scrape along the bottom of the sea around our coasts. Moreover, in some parts of the Channel, small reefs are built up of nothing but the sandy habitations which are fabricated by certain marine worms.

This operation of the formation of new land by animal agents is manifested in the most conspicuous manner and on a gigantic scale, by the coral reefs and islands of which we learn so much in accounts of voyages in tropical seas. It is extremely common to hear, or read, that these masses of land are constructed by coral "insects." As a matter of fact, however, the animals mainly concerned in the formation of these deposits are widely different from insects, while they are very similar to certain marine organisms which abound on our own coasts, and are of much simpler structure than any insects.

A sea anemone.—Scarcely any visitor to the sea-side can fail to be familiar with the peculiar flower-like creatures which are popularly called **sea anemones**[1] (Fig. 199). They are commonly to be found attached to the rocks in little pools of salt water left between tides. The body of the sea anemone is a fleshy sac, more or less cylindrical in shape, and closed at one end, which forms the base, by means of which the creature fixes itself to any solid object. Upon occasion it can quit its hold and, by movement of this fleshy base, is able to crawl over the sea-bottom. In marine aquaria, sea anemones may sometimes be seen creeping up the glass sides of the tank in this fashion. At the opposite

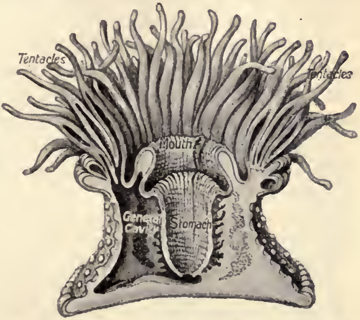

FIG. 199.—Section of a sea-anemone. About one-half natural size, linear measure. From the official "Guide to the Coral Gallery" of the British Museum (Natural History).

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[1] *Anemone*, from the flower so called; from ἄνεμος, *anemos*, wind, in allusion to the flower being easily blown about by the breeze.

end of the cylindrical body there is a mouth, surrounded by a great number of feelers or **tentacles,** disposed in a circle, or more commonly in several circles one within another. So sensitive are these feelers that, if one be lightly touched, they are all quickly drawn in, and the creature shrinks to a small conical mass, looking like a mere knob of jelly stuck to a stone. But, when the feelers are freely spread out, they form a graceful crown, variously coloured and giving the animal a very flower-like appearance, not altogether unlike that of a China-aster, or some other member of that great group of plants represented by our daisies and dandelions.

Structure of sea-anemones.—If any little animal, such as a shrimp, chance to come within reach of the outspread feelers, it is at once carried to the mouth and thrust into a sac, which occupies the centre of the body. Between the walls of this sac and those of the body there is a wide space, so that the arrangement may be compared to that of a pewter inkstand; the inner sac representing the glass vessel which holds the ink, and the rest of the body the body of the inkstand, into which the ink-holder drops. And just as there are holes round the top of the inkstand for holding pens, which holes open into the interspace between the inkholder and the body of the inkstand; so, round the top of the body of the sea-anemone, there are openings, by which the cavities contained within the feelers communicate with the interspace between the inner and the outer sacs. Beyond this point, however, there are two important differences between the sea-anemone and the inkstand. For the inner sac is open at the bottom; and, consequently, the interspace between the inner and the outer sacs, and the cavities of the feelers, are in free communication with the cavity of the inner sac; and, therefore, by means of the mouth, with the exterior. Hence, all the cavities are full of sea-water. In the second place, in the sea-anemone, a number of vertical partitions stretch from the inner sac to the outer wall of the body, whereby the interspace between the two is divided into numerous chambers.

The food which is taken into the inner sac undergoes digestion; its nutritive parts are dissolved and are diffused through the fluid which fills the body and thus serves the purpose of blood; while the indigestible hard parts are cast out again by the mouth. The body of a true insect is divided into segments; it has a digestive canal which does not open into the cavity of the body; it has distinct organs of circulation and respiration, and a peculiarly formed nervous system. None of these features are to be met with in the sea-anemone; which, therefore, is an animal of much lower grade than an insect. Indeed, it is much more nearly allied to the jelly-fishes which float in the sea, and to the fresh-water polypods or polyps of our ponds. The general name of **polyp**[1] is in fact applied to the sea-anemones no less than to the latter.

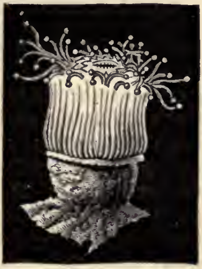

Fig. 200.—Coral polyp from the coast of Devon.

Coral polyps.—The substance of the body of the common sea-anemone is quite soft, and in no species does it acquire a greater consistency than that of a piece of leather. But there are a few animals which live at considerable depths in our own seas, and very many which live in distant parts of the ocean, the structure of which is in all essential respects similar to that of the sea-anemones, but with the addition of a very hard skeleton (Fig. 200). This skeleton, inasmuch as it is formed by the solidification of the base and side-walls of the body of the polyp, necessarily has the form of a cup; and it is termed a **cup coral**, to distinguish it from other kinds of coral, such as the **red coral**, which, though produced by similar animals, are formed in a different manner. Not only are the walls of the body thus hardened, but vertical partitions of the same character extend from the walls of the cup to its centre, in correspondence with the partitions which divide the cavity between the inner sac and the body-wall. The hardening of the lower part of the coral polyp and that of the partitions is effected by the deposition, within their substance, of carbonate of lime extracted from the sea-water in which the animal lives; just as the calcareous salts of the bones are extracted from the milk, and deposited in those parts of the body which are becoming bone, in a growing infant. The deposit converts the base of the polyp into a solid cement,

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[1] *Polyp* from πολὺς, *polus*, "many," and ποὺς, *pous*, "foot"; an animal with several feet or several tentacles.

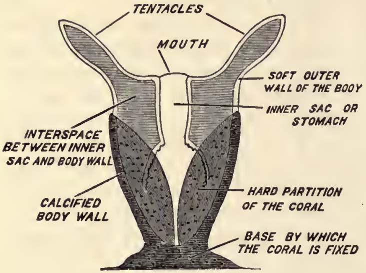

TENTACLES
MOUTH
SOFT OUTER WALL OF THE BODY
INNER SAC OR STOMACH
INTERSPACE BETWEEN INNER SAC AND BODY WALL
HARD PARTITION OF THE CORAL
CALCIFIED BODY WALL
BASE BY WHICH THE CORAL IS FIXED

FIG. 201.—Diagrammatic section of a single cup coral, to show the general structure of the polyp, and the relation of the skeleton to the soft parts.

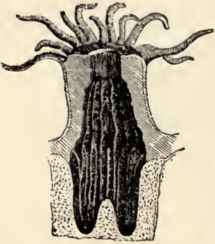


FIG. 202.—Section of a cup coral, showing tentacles and other parts of the soft body, and the solid cup at the base.

which fixes the animal to the surface to which it is attached; and if the polyp goes on growing, not merely in height, but in breadth, while the process of calcification extends as it grows, the coral will necessarily assume the form of an inverted cone as exhibited in Fig. 201. It will be understood that the deposit of calcareous matter does not extend into the region of the feelers, or into the inner sac, so that the formation of the coral skeleton no more interferes with the performance of the functions of the body in the polyp than the development of the bones of a man does with his eating and drinking.

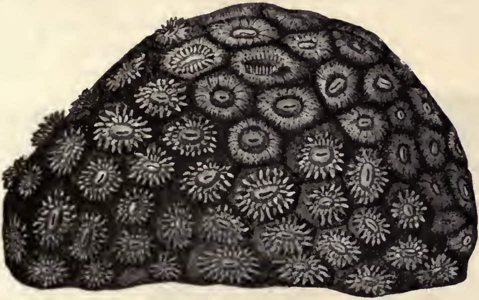


FIG. 203.—Living colony of coral polyps in contact with one another.

Sooner or later the coral polyp dies; then the feelers, inner sac, and all the soft upper parts of the body, and those which cover the skeleton, decay and are washed away, while the skeleton, or **corallite** as it is called when it is formed by a solitary polyp, is left as a contribution to the solid floor of the sea.

Coral growth.—Such solitary coral polyps as have been described give rise to numerous eggs, the young developed from which float away, and sooner or later fixing themselves, take on the form of the parent. Very often they have other modes of multiplication. A coral polyp may give off small buds, each of which grows into a perfect animal with its own stomach, mouth, and feelers, though it remains closely connected with the parent. In other cases, the coral animal spontaneously splits into two halves; and these in turn may divide and subdivide, the product of each division growing into a perfect polyp. By frequent repetition of these processes of budding and splitting, the corals may form masses of great size; in some cases branching like a tree, with separate polyps budding out in all directions; and in other cases spreading into a confused mass, like the well-known "brain-stone coral," which is to be seen in every museum. Since the multiplication of the polyps may go on to an almost unlimited extent, it is evident that the aggregated mass of coral, or **corallum** formed by the combination of numerous corallites, may be of enormous size, although the separate polyps in the coral colony are but small (Figs. 203–205). In fact it is the growth of coral in this manner that forms those masses of land which are known as **coral-reefs** and **coral-islands**.

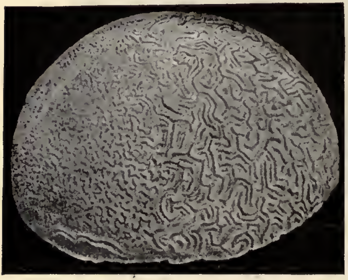


FIG. 204.—Mass of "brain coral." From the official "Guide to the Coral Gallery" of the British Museum (Natural History).

Coral rock.—Such land is popularly said to be "built" by the coral-animals; but it should be understood that it is not a constructive work, like the nest of a bird, or the comb of the bee. The land is simply an accumulation of the calcareous remains, or skeletons, of the coral polyps. The formation of this land is, indeed, very much like the formation of the peat-bog, described in Chapter XIV. It was there shown that the bog-moss dies below, while it continues to grow above; and in like manner the coral polyps die below, leaving their calcareous skeletons, while they continue budding and growing above: hence a coral-island can only be said to be "built" by the polyps in the same sense that a peat-bog can be said to be "built" by the plants of the remains of which it consists.

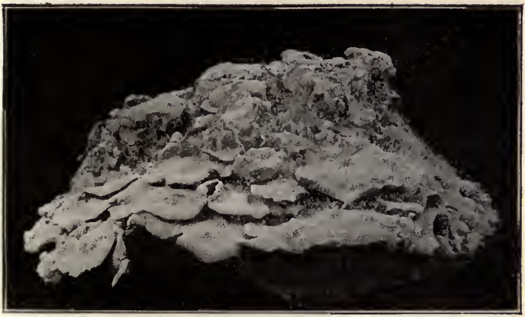


FIG. 205.—Mass of coral weighing about 13 cwt. From the official "Guide to the Coral Gallery" of the British Museum (Natural History).

Many islands in tropical seas are skirted by low banks of coral-formed rock. At high tide the surface of the rock is for the most part submerged, and its position is then marked only by a white line of heavy breakers. But at low water the surface is more or less exposed, forming a broad and bare platform, which rises slightly above sea-level.

Some islands are completely bordered by a margin of this coral-rock, while others are fringed only at certain points. Where a stream runs down from the land, and carries sediment to the sea, the reef is generally absent, for the coral polyps do not thrive in muddy water.

Coral reefs.—Rocky ridges, which fringe a shore in the manner just described, are known as **fringing-reefs.** In other cases the coral-rock is not directly attached to the coast, but stands off at some distance, so as to form a barrier, perhaps many miles from land. Such reefs are consequently called **barrier-reefs.** Between the coast and the reef there is a channel of comparatively shallow water, forming a harbour, to which entrance is gained by a breach here and there in the reef, the reef itself constituting a natural breakwater. Patches of coral rock, forming small isolated reefs, may be scattered about the quiet channel,

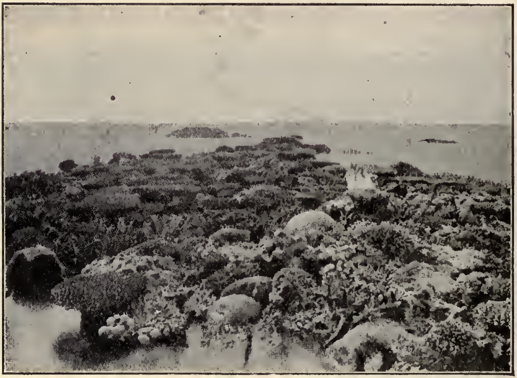


FIG. 206.—Living coral on the Crescent Reef, Great Barrier Reef, Australia. From a photograph by Mr. W. Saville-Kent.

and the barrier itself may be broken up into a chain of detached reefs. Along the north-eastern coast of Australia there is a chain of these barrier-reefs stretching for a length of about 1,200 miles, and standing at an average distance of twenty or thirty miles from the coast (Fig. 206). The channel between this **Great Barrier Reef** and the land is termed "the inner passage," and has a depth of about twenty or five-and-twenty fathoms; while outside the barrier-reef the depth of the sea suddenly increases to many hundred fathoms.

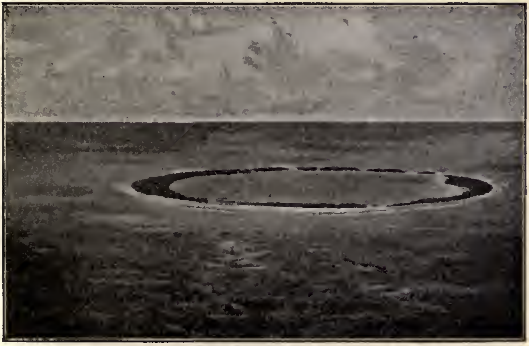
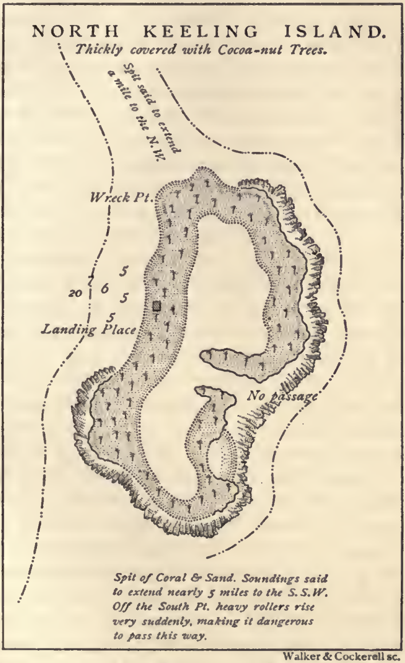


FIG. 207.—An atoll. Bird's-eye view of Caroline Island, one of the Marquesas group, South Pacific.

In addition to the fringing and barrier-reefs, there is yet another kind, differing from those principally in being quite isolated from other land. The coral-rock thus forms a true island, rising from the sea usually as a low strip of land, more or less ring-shaped, but generally of irregular outline. In places, the strip of coral-land may bear a rich growth of cocoa-nut palms and other tropical forms of vegetation: while inside the rim of land there is a shallow lake, or **lagoon,** of clear green water, which strikingly contrasts with the dazzling white coral-rock of the beach. Access to the lagoon is gained by a gap in the shore, and thus the island generally presents a horse-shoe shape. Several openings may occur in the belt of land, and the island consequently becomes broken up into a chain of islets. These coral islands are plentifully scattered through the Pacific and Indian Oceans, and are often known under the Maldive name of **atolls** (Figs. 207, 208).

The building of coral-land.—In explaining the formation of coral-land, it should be remembered that the corals themselves are powerless to raise the land above low-water mark, for the polyps perish when exposed above water. Dry land is, however, formed mechanically; blocks of dead coral being broken off by waves from one part of the rock, and piled up upon another. The loose blocks, together with coral-sand and coral-mud, produced by the tear and wear of the coral-rock, are cemented into compact masses by the deposit of carbonate of lime previously held in solution. In the case of fringing-reefs the seaward, and in that of atolls the windward, side of the mass of coral is usually the highest, for it is here that the coral polyps flourish most luxuriantly; while the dash of the breakers during storms tears off fragments of the coral-rock, and heaps them up on this side. It should be borne in mind that the land is not entirely formed of corals, since other creatures living in the lagoon and on the banks of the reef contribute their remains to swell the mass. Vegetable life too is not without its effect on the formation of the new land; and indeed the outer edge of a reef is often, in large measure, formed of **nullipores,** a kind of seaweed, the tissues of which are strongly impregnated with carbonate of lime.

Distribution of coral organisms.—Although corals of some kinds may be found in almost all seas, those particular species which grow together in masses, and thus form reefs and islands, are limited to the warmer parts of the world. Reef-forming coral animals are restricted to


NORTH KEELING ISLAND.
Thickly covered with Cocoa-nut Trees.
Spit said to extend a mile to the N.W.
Wreck Pt.
5
20
6
5
5
Landing Place
No passage
Spit of Coral & Sand. Soundings said to extend nearly 5 miles to the S.S.W. Off the South Pt. heavy rollers rise very suddenly, making it dangerous to pass this way.

Walker & Cockerell sc.

FIG. 208.—Map of a coral island, copied from an Admiralty chart.

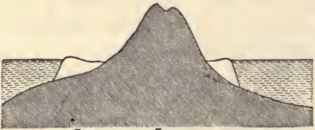
waters in which the lowest winter temperature never falls below 68° F. (20° C.). If, then, a line be drawn through all parts of the ocean north of the equator, where the coldest month has this average temperature, and a similar line south of the equator, they will include a zone within which all the coral-reefs of the world are situated. It need hardly be said that these lines will not be straight lines running in circles round the world, like parallels of latitude, but will be irregular lines, rising in one part and falling in another, according as the temperature is locally affected by the presence of ocean-currents or by the proximity of land. This belt of warm water, congenial to the coral-makers, never extends beyond about 30 degrees from the equator.

Limitations of depth.—Though the reef-building corals abound in many parts of this zone, they are not found in all parts of it. They are absent, for example, on the western coasts of Africa and America; and where great rivers debouch, the sediment and the fresh water, which they pour into the sea, interfere with the growth of the coral polyps. Moreover, reef-forming corals are restricted, not only in their superficial distribution, so as to be limited to certain *latitudes*, but also in their vertical distribution, so as to be limited to certain *depths*. Indeed, the needful conditions for the growth of the polyps are found only in comparatively shallow water; for the food of corals is derived entirely from algæ, and the depth at which these plants can live is determined by the depth to which light can penetrate sea-water. From the observations of Charles Darwin, it appears that reef-building corals do not flourish at greater depths than between 20 and 30 fathoms, and are for the most part restricted to about 15 fathoms of water. Knowing this, it might not unnaturally be assumed that coral-reefs and coral-islands would always be confined to shallow seas. As a matter of fact, however, soundings outside a barrier-reef or an atoll often show an enormous depth of water, the outer edge sinking down abruptly like a coral-wall. The early navigators knew that coral-islands were not unfrequently surrounded by very deep water; but this fact presented no difficulty, until naturalists became aware of the small vertical range to which the living corals are limited. Various attempts were then made to reconcile the two apparently opposed facts, and in 1837 Darwin advanced an ingenious hypothesis which apparently not only solved the puzzle, but also brought the several classes of coral-reefs into close relation with each other.

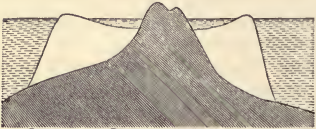
The subsidence theory of coral-reefs.—According to Darwin's view, the coral-rock has in all cases been originally formed in water not deeper than about 20 fathoms; and when found at greater depths it must have been carried down by subsidence of the rocky foundation on which the polyps lived and died.

It has already been shown that coral-polyps can multiply by processes of budding and splitting; but it should be added that they can also multiply by means of germs, which are thrown off from the parent as free-swimming bodies. Suppose that some of these embryonic corals settle upon a sloping shore, in shallow water, where the conditions of life are favourable; there they may go on multiplying, until they form masses of considerable extent, skirting the land, but never extending seawards to a depth of more than 20 or 30 fathoms. Let the land, with its little fringing-reef, now slowly sink; that part which is carried down lower than about 30 fathoms will consist of nothing but dead coral; but the upper part of the reef will continue to grow, and, if the subsidence be not more rapid than the upward growth, the level of the reef will appear to remain stationary, at about the sea-level. It has been said that the coral-polyp flourishes best at the outer margin of the reef, where it is bathed by the surf. For this and other reasons, the reef is highest at this edge; while, between the outer margin of the reef and the shore, there is a channel formed by the entry of sea-water during subsidence. In fact, the fringing-reef, as it has been slowly carried down, has become converted into a barrier-reef. This will be easily understood by reference to the sections in Fig. 209.

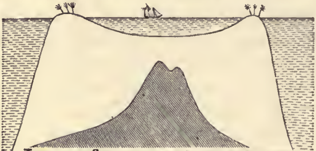
Outside the barrier, on its seaward edge, there may be a great depth of water, varying according to the extent to which subsidence has gone on. By continued subsidence of an island encircled by a barrier, the lagoon becomes wider and wider. At length only a few rocks may stand up in the centre of the lake ; even these may at last disappear, leaving nothing but a sheet of water surrounded by the reef, and the barrier in this way becomes converted into an atoll.



First stage: Fringing-reef.



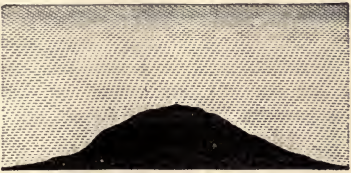
Second stage: Barrier-reef, with intervening lagoon.



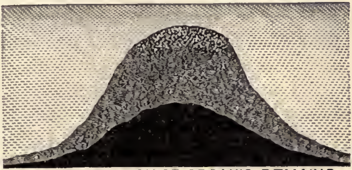
Third stage: Coral island, or atoll, with central lagoon.

Fig. 209.—Stages of development of coral reefs, according to the subsidence theory.

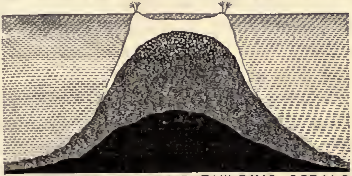
The elevation and dissolution theory.—According to Darwin's theory, barrier-reefs and coral-islands indicate where the land is, or has been, slowly sinking; but evidence obtained by later investigators has shown that in many cases the reverse is probably the case. A theory put forward by Sir John Murray in 1880, and since substantiated by the results of studies carried on by careful naturalists in various parts of the world, suggests that the land on which reef-corals have built has been brought within their range of operations by elevation due to submarine volcanic action or by the deposition of remains of organisms which live and die below the depth to which reef-building corals are limited. Instead of beginning with a fringing-reef which becomes converted into a barrier-reef and then an atoll as the land subsides, it is believed that an atoll represents a mass of coral rock which has been brought to the surface by the accumulated remains of polyps, and of which the central parts have been dissolved away by the water so as to produce a hollow which forms a lagoon, while the rim is continually growing out-



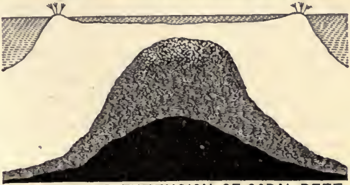
(1) SUBMARINE ELEVATION



(2) ACCUMULATION OF ORGANIC REMAINS



(3) SUMMIT OF REEF-BUILDING CORALS



(4) OUTWARD EXTENSION OF CORAL REEF

FIG. 210.—Stages in the development of coral reefs, according to the elevation and dissolution theory.

ward. In the lagoon the supply of food is limited and the growth of coral polyps is therefore less rapid than on the outer margin washed by the currents of the open sea. While the outer edge is being extended seaward, the dead coral in the lagoon is being dissolved by the water and washed away, so that though the coral-ring expands as time goes on, its breadth remains approximately the same (Fig. 210).

The formation of barrier-reefs from fringing-reefs can also be explained by the erosion of the landward edge—where the polyps grow but sparingly—and the extension of the sea faces of the reefs, where these organisms have their fullest development. Some of the barrier-reefs of the Society Islands, of Fiji, and of the Carolines afford good evidence that the wide and deep lagoons which separate them from the land mass have been formed in this way, by the erosion of a broad fringing-reef flat. Many barrier-reefs flank volcanic islands and are underlaid by volcanic rocks, while others are on platforms formed by outlying parts of the adjoining land masses, which crop out as islands and islets in the very outer edge of the reefs.

Probably no single explanation will account for the formation of all types of coral reefs, but the observations of recent years clearly show that only in a few exceptional cases do reefs owe their existence to the subsidence of the land around which they formed only a fringe. In some cases the platform upon which the superstructure of coral has been erected consists of limestones and volcanic rocks which once rose above sea-level and have been worn down by denudation; in others the foundation consists of the remains of deep-sea organisms on submarine mountains and elevated plateaus, or on the flanks of mounds produced by submarine eruptions. Finally, instead of being situated on subsiding land, the great coral reef regions occur, with few exceptions, in areas which are being elevated and are thus brought within the sphere of activity of reef-building organisms.[1]

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[1] Several important investigations of coral-reefs have been made in recent years, and the latest results appear in the following publications: (1) *The Atoll of Funafuti: Report of the Coral Reef Committee of the Royal Society*, 1904. (2) *The Fauna and Geography of the Maldive and Laccadive Archipelagoes. Notes on Coral Formations.* By J. Stanley Gardiner (Cambridge: University Press. 1902–1903). (3) *The Coral Reefs of the Tropical Pacific.* By Prof. A. Agassiz. *Memoirs of the Museum of Comparative Zoology at Harvard College.* Vol. xxviii. 1903.

CHAPTER XVI

SUBMARINE DEPOSITS AND RELATED ROCKS

Submarine studies.—The operations of the reef-building coral polyps are carried out on a gigantic scale. The Australian barrier-reef alone spreads a constantly increasing deposit of coral limestone over an area larger than that of Scotland;[1] while the totality of the surface over which coral reefs are spread in the Pacific Ocean exceeds that of Asia. Moreover, reefs and atolls are conspicuous objects, forcing themselves on the attention of the traveller by their beauty and their singularity, and awakening that of the navigator by the dangers which they create. But the conversion of the contents of the ocean into solid rock is constantly taking place, over a still greater area, and probably as rapidly, by agents which are inconspicuous, and indeed for the most part invisible; not only by reason of their minuteness, but because the results of their work accumulate, not in shallow waters, but at the bottom of the deep sea. Out of sight, they would be also out of mind, if various circumstances had not of late years led to the careful exploration of the depths of the ocean.

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[1] The area of the barrier-reef is estimated to be 33,000 square miles; that of Scotland is 31,324 square miles.

Almost everything that is known about the deep-sea bottom and its inhabitants has been learnt since the middle of the nineteenth century. Explorations of the sea have been actively carried on in various parts of the world; and the valuable series of observations obtained during the expeditions of H.M.S. *Challenger* and other vessels equipped for marine investigations has given us exact information of its nature, at a series of stations, in all the great oceans.

Sounding the ocean.—In the ordinary method of sounding, or ascertaining the depth of the sea, a leaden weight is attached to the end of a graduated line, and rapidly run out until the weight strikes the bottom. To procure a sample of this bottom, the lead is "armed"; that is to say, the bottom of the weight, which should be slightly hollow, is covered with tallow, and a small quantity of the mud or other material at the bottom sticks to this grease, and may thus be brought up for examination. Such rude means are sufficient for sounding in shallow water, but more complicated instruments are required for deep-sea soundings. Most of these instruments act upon a principle first suggested by Lieutenant Brooke, of the U.S. Navy—that of causing the weight to detach itself from the line on reaching the bottom. The sounding-line thus runs down carrying a weight, but comes up free, bringing only a sample of the bottom, which is collected from the floor of the sea in a cup, or a tube, or a scoop.

The "Hydra" sounding machine.—Without referring to the various modifications of sounding apparatus which have been employed by successive deep-sea expeditions,[1] it will be sufficient to describe the sounding machine which was very largely used during the voyage of the *Challenger*. This is represented in Fig. 211, which also shows a section of the instrument.

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[1] Descriptions and figures of these instruments will be found in *The Depths of the Sea*, by Sir C. Wyville Thomson. The sounding apparatus itself may be seen in the Victoria and Albert Museum at South Kensington.

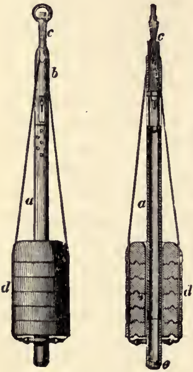

Fig. 211.—Deep-sea sounding apparatus used by the *Challenger.*

The apparatus consists of a metal tube *a*, mostly of iron, five and a half feet in length, and two and a half inches in diameter. Its upper end is furnished with a brass cylinder, *b*, in which a heavy piece of iron works up and down, like a piston in a cylinder. At *c*, this iron is furnished with a shoulder, which carries the iron-wire sling to which the sinking-weights are attached. These sinkers, *d*, are made of iron, cast in the form of cylinders, each with a central hole; they are provided with teeth and notches, so as to fit one into another; and thus several may be fitted together, forming a compact mass perforated by a central canal, through which the tube passes. As the instrument runs down, water enters the tube *a*, at its open end *e*, and passes out through holes in the upper part. On striking the bottom, the tube sinks into the mud or other material, and a small quantity enters; and this is prevented from escaping by means of a pair of butterfly-valves, opening inwards, which are attached to the bottom, *e*. When the floor of the sea is touched, the brass cylinder, *b*, is pushed up, and striking the shoulder, *c*, of the iron piston, throws off the sling, and thus releases the weight. Thus, when the line to which the instrument is attached is hauled in, it carries to the surface nothing but the tube full of the sea-bottom. It is by means of such instruments that the deep sea has been sounded, and samples of the bottom brought to the surface for scientific examination.

The bed of the Atlantic.—The careful soundings made during these surveys revealed the remarkable configuration of the Atlantic sea-bed. This is shown in Fig. 212, which represents the contour of the floor of the sea between Valentia Island off Ireland, and St. John's in Newfoundland. It will be seen that there is a gradual downward slope from the Irish coast, for a distance of about 200 miles; then there is a more rapid descent leading to a vast undulating plain which stretches across the ocean, until it reaches a distance of about 300 miles from Newfoundland, and from thence it gradually ascends towards the American coast. In the diagram this descent looks like a steep cliff. But this is a deception arising from the exaggeration of the vertical height. Drawn to a true scale as in *D*, Fig. 212, the inclination of the slope is seen to be not more than 1 in 25, or that of a hill of moderate steepness. If it were a mere question of gradients, a wagon could be driven along the sea-bottom from Ireland to Newfoundland without any difficulty. This great submarine plain, which has been called the **telegraph plateau,** has a width of more than 1,000 miles, and an average depth of more than 1,000 fathoms.

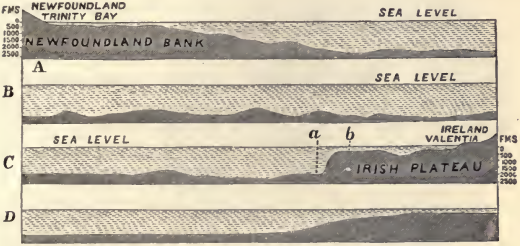

FIG. 212.—*A*, *B*, *C* taken together represent a section of the Atlantic between Newfoundland and Ireland. Vertical scale about fifteen times horizontal scale. The part between *a b* off the plateau is drawn to true scale at *D*.

Nature of calcareous ooze.—The bed of the Atlantic is almost uniformly covered with a wide-spread deposit of fine creamy or greyish mud, generally called **ooze.** When this mud is dried, it hardens into a grey friable substance, which may be used for writing on a board, as chalk is used. Moreover, when any acid is poured upon the mud, the greater part of it dissolves with effervescence, just as a piece of chalk would do; and it can readily be ascertained that the ooze, like chalk, consists mainly of carbonate of lime.

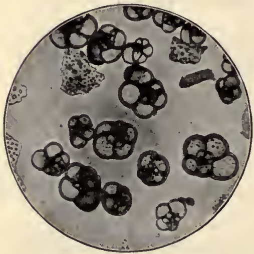
FIG. 213.—Ooze from the bed of the Atlantic: depth 1,600 fathoms. Magnified 50 diameters. From a photograph by Mr. J. E. Barnard.

This calcareous ooze, however, is not mere mineral matter; for when a little is placed under the microscope, the greater part of it is seen to consist of such bodies as those represented in Fig. 213. Each of these consists of several globular chambers, one of which is smallest and one largest, while the others are of intermediate dimensions, disposed around a common centre, and adherent together. Each chamber has an opening in the face which is turned towards the centre; and in the living state all the chambers are filled with a protoplasmic substance, which spreads over the surfaces of the chambers, and sends out long radiating contractile threads. The walls of the chambers are hard and brittle, from the large quantity of carbonate of lime which they contain; and in the smaller chambers they are very thin and quite transparent. In the larger, they become thick, and the outer part of their substance acquires a prismatic structure. In specimens taken from the sea with great care, the outer surfaces of the chambers are beset with long slender calcareous processes, like threads of glass; but these very readily break off.

Globigerina ooze.—The bodies thus described are the skeletons of animals of a very simple character, known as *Globigerina bulloides*, belonging to the group which has been named the **Foraminifera**[1] (Fig. 214) in consequence of the numerous perforations usually visible in their hard parts.

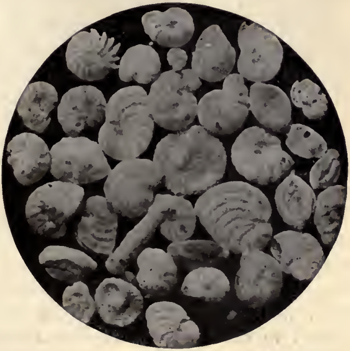

FIG. 214.—Group of various forms of Foraminifera, magnified 25 diameters. From a photograph by Mr. J. E. Barnard.

Many of these organisms and also certain free-swimming molluscs termed **Pteropods**, having calcareous shells, live at or near the surface of the ocean where the temperature never falls below 60° F., and when they die their thin calcareous shells fall to the bottom of the sea. Other forms pass all stages of their life on the ocean floor where their shells are found, so that the marine deposits contain not only the remains of animals which lived their whole life in tropical and sub-tropical regions, but also of animals which lived at a temperature only two or three degrees above the freezing point of fresh water. Wherever the ocean floor is dredged, except in the polar regions, the shells of various types of Foraminifera are found mingled with the remains of other organisms.

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[1] *Foraminifera*, Lat. *foramen*, an aperture; and *fero*, I carry.

Calcareous deposits on the ocean floor.—Over the whole of this enormous extent of ocean, therefore, these shells and skeletons are accumulating, many of them falling from the surface through perhaps two or three miles of sea-water as an incessant rain of dead matter upon the ocean floor. It is probably an over-estimate if we assume that the average bulk of the calcareous matter contained in each full grown Globigerina amounts to $\frac{1}{1,000,000}$th of a cubic inch. Nevertheless, we have seen that pluvial denudation, however slow and insignificant the wear and tear of rain and rivers on dry land may appear to be, effects a vast destruction of the solids of the globe when continued through long ages; and this prepares the mind to view, in the incessant downpour of lime-drizzle in the ocean, a no less potent agent of reconstruction. If we suppose that the total thickness of the deposit of solid matter on the sea-bottom, arising from the accumulated remains of Foraminifera, is as much as one-tenth of an inch a year; then, if the present state of the Atlantic and Pacific Oceans has existed for only 100,000 years, this apparently unimportant operation will have sufficed to cover their floors with a bed of limestone no less than eight hundred feet thick.

Although the Globigerina shells (Fig. 215) constitute the greater part of the substance of the ooze, the remains of other organisms are found with them. Among these, other Foraminifera are very common; and especially one form, the **Orbulina,** which is very closely allied to, if not a condition of, the Globigerina itself.

Besides these, there are innumerable multitudes of very minute saucer-shaped disks, termed **coccoliths,** which are frequently met with associated together into spheroidal aggregations, known as **coccospheres** (Fig. 216). Little is known even now about the life history or affinities of these minute organisms, but they are usually regarded as simple algæ, or as the spore-cases of algæ.

Other minute calcareous bodies are called **rhabdoliths**; they differ slightly from coccoliths in their shapes, and their nodular aggregations form **rhabdospheres.**

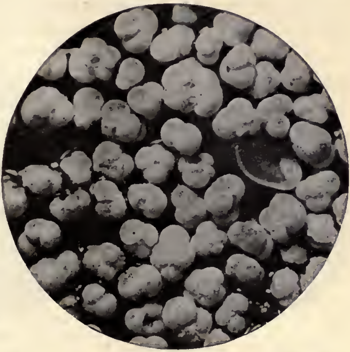

FIG. 215.—Globigerinæ. Magnified 25 diameters. From a photograph by Mr. J. E. Barnard.

Siliceous deposits.—Calcareous organic remains constitute the greater part of the ooze brought up from the floor of the Atlantic, but at the bottom of parts of the Pacific and Indian Oceans and in the Antarctic deposits are met with containing multitudes of siliceous skeletons, some of which belong to simple animal forms, such as **Radiolaria** (Fig. 217) and certain species of sponges, which are, however, unlike those of commerce, while others are vegetable organisms, belonging to the group of **Diatoms** (Fig. 218) described in Chapter XIV. The Diatoms and the Radiolaria inhabit the surface of the ocean, along with the Globigerinæ and Orbulinæ, but the sponges live at the bottom, and their relics are represented by siliceous

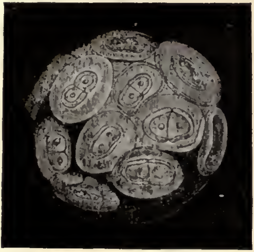

FIG. 216.—A coccosphere. Magnified 1,000 diameters.

spicules. Here and there, the remains of other animals which inhabit the depths of the sea, such as starfishes, sea-urchins, and various shell-fish, are also embedded in the ooze, and contribute to the solid submarine deposit.

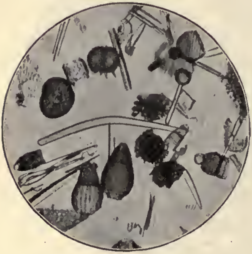

FIG. 217.—Radiolarian ooze. Magnified 50 diameters. From a photograph by Mr. J. E. Barnard.

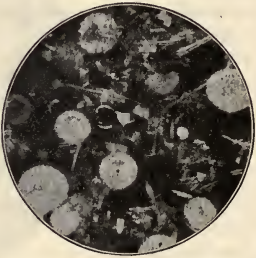

FIG. 218.—Diatom ooze. Magnified 40 diameters. From a photograph by Mr. J. E. Barnard.

Dissolution of Globigerinæ.—It has been seen that living Foraminifera are found in the uppermost stratum of the sea, all over the warm and temperate parts of the world. Hence, it would seem to follow, that Globigerina-ooze should be found covering the bottom of the sea over the whole of these regions; and, in fact, it is met with at all depths between 250 and 2,900 fathoms, over an immense extent of both the Atlantic and the Pacific Oceans.

But the most widely distributed deposit on the sea-bottom is not Globigerina-ooze, but a **red mud**, which appears to be nothing but clay in a very finely divided state. This deposit is met with at a great distance from land and at a very great depth, more than 2,500 fathoms in fact; and the naturalists of the *Challenger* observed that, in passing from the adjacent region covered with the ordinary Globigerina-ooze, into one of these red-clay areas, a region covered with a sort of **grey mud** (grey ooze), intermediate in its character between the Globigerina-ooze and the red clay, was traversed. Where the grey ooze began, the Globigerina shells appeared to be corroded, as if they had been attacked by an acid; and, as the red clay was approached, they became more and more fragmentary, and at length altogether disappeared.

There can be no doubt that the remains of surface Foraminifera fall over the area occupied by the grey ooze and the red clay just as persistently as elsewhere. What then becomes of the shells? There seems to be no escape from the conclusion that the calcareous matter of which they are composed is dissolved away. The Globigerinæ are so minute, that their skeletons must take a great length of time to subside through the three or four miles of water which overlie the deeper sea-bottoms. But sea-water contains much carbon dioxide in solution, and it has already been seen that carbonate of lime, especially if finely divided, is soluble in such water. Hence, it is highly probable that

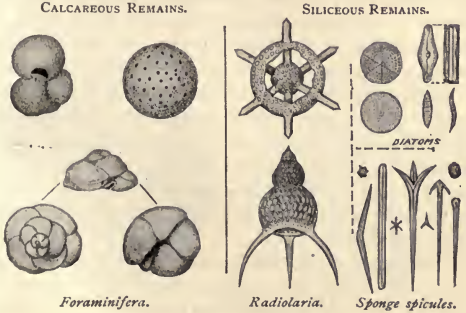
CALCAREOUS REMAINS.
SILICEOUS REMAINS.
DIATOMS
Foraminifera.
Radiolaria.
Sponge spicules.

FIG. 219.—Typical remains found in deep-sea deposits.

the foraminiferal shower is in part redissolved before it reaches the bottom; and that, other things being equal, the greater the depth, the greater will be the loss suffered in this manner.

Origin of red clay deposit.—It has been suggested that the red clay is the residuum left after the Globigerinæ have been dissolved; but there is no sufficient evidence that pure and clean Globigerina shells contain any appreciable proportion of such mineral matter.

The principal constituents of the red clay are such as would be derived from the disintegration of pumice and volcanic dusts. The material thus appears to be due to the decomposition of volcanic ejections which have been borne about by winds, and finally scattered over the surface of the ocean. Fragments of volcanic minerals are everywhere found in the Globigerina ooze; and it is highly probable that the products of "volcanic showers" are intermixed with the foraminiferal deposit all over the ocean. In those localities in which the Foraminifera are dissolved before they reach the bottom, the volcanic minerals remain as the sole constituent of the ooze, and by their decomposition give rise to the red clay. Mingled with the red clay are found numerous shark teeth, and ear bones of whales, and also particles of iron and nickel believed to represent the dust of shooting stars which have fallen through our atmosphere from outer space.

Ocean bed and dry land.—From what has been said it follows that if, in consequence of one of those movements of upheaval to which reference has been made, the present bed of the Atlantic were raised to the surface and became dry land, the many thousand square miles of new dry land thus produced would be found to be covered, for an unknown thickness (amounting possibly, and indeed probably, to hundreds of feet), with a bed of softish limestone. The great bulk of this calcareous rock would be made up of entire or fragmentary Globigerina and Orbulina shells; but it would contain in addition other Foraminifera, shells of shellfish, remains of starfishes and sea-urchins, and of such other animals provided with hard skeletons as are now living in the Atlantic. It would in fact be a highly "fossiliferous" limestone, with more or less silica, in the shape of Radiolaria skeletons and sponge spicules, scattered through its mass, and would constitute an element of no small magnitude and importance in the composition of the earth's crust.

Chalk and ooze.—A close resemblance exists between some of the rocks which make up the dry land of the earth and the deposits at present found on the floor of the ocean. There is little doubt that the chalk, which forms the North and South Downs and lies beneath London as a bed several hundred feet in thickness, represents the mud of an ancient sea-bottom; for multitudes of remains of animals have been obtained from it, most of which belong to such groups as are exclusively marine at the present day. The area once occupied by the chalk was therefore, at one time, covered by sea. And it may be further concluded that it was at some distance from any extensive land, inasmuch as the chalk contains no such mixture of clay and sand as would be derived from denudation. But there is another

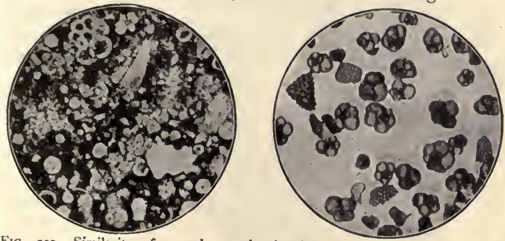

FIG. 220.—Similarity of organic remains in chalk and Atlantic ooze. From photographs by Mr. J. E. Barnard.

reason for believing that the chalk ocean was fairly deep; that is to say, over 100 fathoms. If a slice of chalk is cut, ground thin, and mounted in Canada balsam, so as to become transparent, shells of Foraminifera may almost always be detected in it, and sometimes they abound. The commonest form is a Globigerina, indistinguishable from that which constitutes the bulk of the Atlantic ooze (Fig. 215). Moreover, coccoliths and coccospheres are plentiful in the chalk, which differs, however, from the ooze in the greater ratio of granular particles, without any definite shape, to recognisable organic remains; and in the absence of those siliceous shells and skeletons, which are so constant in the ooze (Fig. 220).

Many extensive beds of limestone and chalk-marls also resemble deep-sea oozes, both in microscopic character and chemical composition.

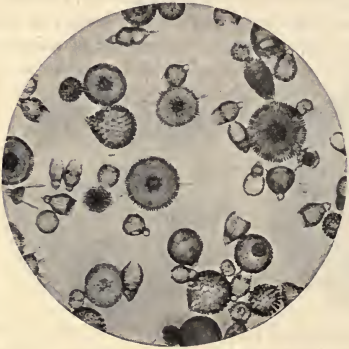

FIG 221 Radiolaria. Magnified 25 diameters. From a photograph by Mr. J. E. Barnard.

Radiolaria in rocks.—There is evidence that when the massive deposits of carboniferous limestone of England were being formed on what was then an ocean floor, there existed a deeper ocean towards the south-west part of the area, where siliceous organisms predominated. Dr. Hinde and Mr. Howard Fox have found that certain beds in Devon, Cornwall, and West Somerset contain abundant remains of Radiolaria, mostly in the form of siliceous casts of the original organisms. Deposits of a similar character to these fossil beds are now known only from great oceanic depths; hence the conclusion is reached that the radiolarian rocks of the West Country were laid down in the deep water of an open sea at some distance from a shore line.[1]

Radiolaria are also found in certain chert beds in the south of Scotland; and in the West Indies earthy deposits occur which consist largely of the relics of these animals and of various Foraminifera. But though many strata are known which closely resemble oceanic oozes containing Foraminifera, Radiolaria, sponge spicules, and diatoms, none of the rocks which make up the land surface of the earth are identical with the accumulations of red and grey clay which are being formed in the deepest parts of the ocean. About 70 per cent. of the ocean floor has a depth greater than two thousand fathoms; and the deposits upon it have no formations like them upon the land. It therefore appears probable that the parts of the ocean bed below the two thousand fathom line represent permanent depressions in the earth's crust, and have never been raised above sea-level, this conclusion being the same as that previously arrived at from other considerations (p. 233).

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[1] Radiolarian Rocks in the Lower Culm Measures of Devon, Cornwall, and West Somerset. By Dr. G. J. Hinde and Mr. Howard Fox. *Quarterly Journal of the Geological Society*, November, 1895.

CHAPTER XVII

GEOLOGICAL STRUCTURE AND HISTORY

Agents of change.—In the preceding chapters, the general character of our rivers and the form of the surface which they drain have been considered; their waters have been followed to the sea, and thence, by way of the atmosphere, back to the land surface; while the atmosphere, and the waters of the land and sea, have been traced back to the elementary bodies of which they are composed. The rivers, and the rains which feed them, were next considered as a grinding and dissolving machinery, by which the surfaces of the river basins are being insensibly worn away and their materials carried down to the ocean; while the sea, so far as it washes the banks and shallows of the estuaries and of the adjacent coasts, was shown to be a no less persistent destroyer of the dry land. And then, seeing that all rivers and all oceans are engaged in the business of denudation and dissolution, it became a matter of interest to discover what natural operations, if any, tend to compensate this constant wear and tear of the dry land. Such compensating agents were found in the forces which tend to raise submerged land; in volcanoes, which transfer matter from the interior to the surface; and, lastly, in living matter, which on the whole tends constantly to increase the solids of the globe, at the expense of its fluid and gaseous components.

With these conceptions of the general nature of the agents which are now at work in modifying the crust of the earth, it will be possible to start with profit upon a new series of considerations.

Soil and subsoil.—Our country presents, as has been seen, a surface diversified with hills and valleys; this surface is generally covered with a comparatively thin layer of soil, which in many places has been more or less altered in character by the builder, the road-maker, or the farmer, and is then known as "made ground." But beneath this lies the subsoil, which forms the uppermost part of the solid floor.

It has been seen that the subsoil varies very much at different places, being here gravel or sand, there clay, in other places chalk or other kinds of calcareous rock, or sandstone, granite, &c. Moreover most of these materials are arranged in layers or strata; so that, if a vertical cutting were made deep into the earth, the faces of the section would generally present a succession of layers one above the other. It has been mentioned that quarries and railway cuttings, here and there, afford the opportunity of examining the strata in their natural relations and order of superposition. The shafts and galleries of mines give us a view of deeper stratification; and in boring for wells, artesian or other, the succession of strata is indicated by the fragments drawn up, although the bores or holes are too narrow to allow the strata to be inspected *in situ*. In some districts the stratification is shown on a grander scale, where the denuding action of water and ice has worn down the rocks and left their rough edges exposed in cliffs and mountain sides.

Arrangement of strata.—As explained in previous chapters, there is no doubt that these strata were originally formed or deposited in a horizontal position, with only slight irregularities, due in some cases to the action of currents upon the sedimentary material being laid down (Fig. 222); and yet they are seldom found lying horizontally for any great distance, for in course of time the movements of the earth's crust tilt most of the strata in one direction or another. Sometimes the tilting is very considerable, causing strata to rise to the surface in one direction, while in the opposite direction they

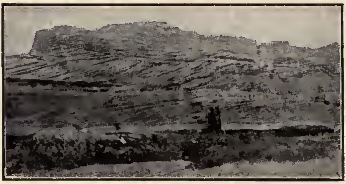


FIG. 222.—Triassic sandstone at Hilbre Island, Cheshire, showing the effect of currents upon the distribution of the layers of a deposit of sand. From a photograph by Mr. C. A. Defieux.

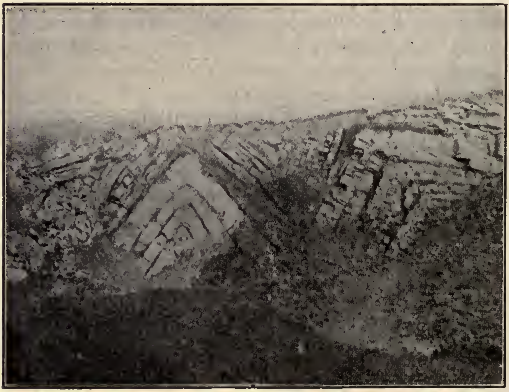
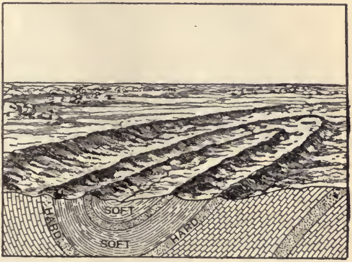
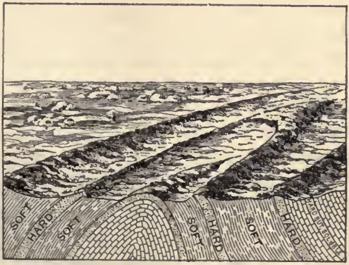


FIG. 223.—Folded carboniferous limestone in Draughton Quarry, near Skipton, Yorks. From a photograph by Mr. J. C. Christie.

dip and disappear beneath overlying rocks. Beyond the place where they dip out of sight their presence may often be demonstrated by boring; or they may rise to the surface again miles away. It was mentioned on page 221 that, when rocks are folded in this way, the bottom or concave part of the curve is called the **synclinal**, and the apex or convex part the **anticlinal.** It is easy to understand that the effect of denudation upon layers of hard and soft rock folded in these ways may produce such undulating surfaces as are represented in Fig. 224.



SYNCLINAL FOLDS.



ANTICLINAL FOLDS.

FIG. 224.—Crumpled beds of rock and the surface features produced by the different degrees of denudation of hard and soft layers. From *Bulletin* No. 150 of the U.S. Geological Survey.

Rocks of recent origin.—A correct understanding of the development of the earth's crust is best acquired by studying first the rocks that are in process of being deposited; passing thence to others the growth of which is completed, but which are nevertheless comparatively recent in origin; and afterwards considering older and still older rocks. By this method we learn how time gradually modifies the rocks, through the action of chemical changes and the movements of the earth's surface.

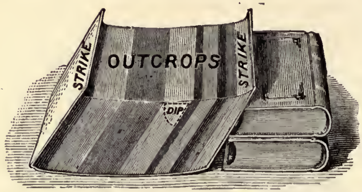


FIG. 225.—Illustration of outcrops, strike, and dip by means of an upturned book.

The deposition of mud, gravel, &c., may be observed in most of our rivers and estuaries, and some of these materials, after the lapse of ages, will become rocks. But for the study of rocks, the deposition of which is complete though comparatively recent, there is no better district in the British Isles than the valley of the Thames. For in the neighbourhood of London and the Thames estuary we find the most extensive area of later or **Tertiary rocks** in Britain, and as we journey thence to other parts of the country we pass over the earlier rocks in remarkably regular succession, as they emerge one after another from beneath the later-deposited rocks.

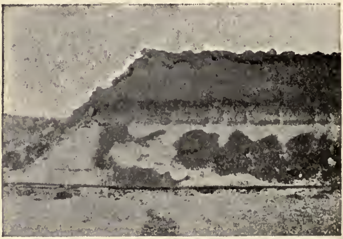


FIG. 226.—Section on the marsh between Tottenham and Higham Hill, River Lea. Upper layers consist of dark silt, peat, and clay, eight feet thick; these rest upon a layer of stratified gravel five feet thick. Reproduced, by kind permission, from a photograph by Mr. H. W. Monckton.

River gravel and loam.—Much of the subsoil in and about London is formed of gravel which the river washed down from rocks higher up the valley, and deposited over a large area, when the present land-surface was at a lower level and formed the floor of the estuary. In addition to the gravel there are deposits of

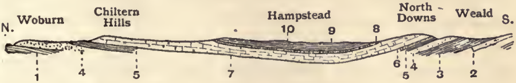


FIG. 227.—Section across the London basin. (H. B. Woodward.) Alluvium and valley gravel not shown. 10, Bagshot beds; 9, London clay; 8, Blackheath beds, Woolwich and Reading beds, Thanet beds; 7, chalk; 6, upper greensand; 5, gault; 4, lower greensand; 3, weald clay; 2, Hastings beds; 1, Oxford clay.

loam, or soft sandy clay, one variety of which is known as **brick-earth,** since it is largely worked by brick-makers. This loam seems to have been deposited in broad shallow areas of the ancient estuary, where, owing to the comparative stillness of the water, the mud and sand had time to settle at the bottom.

London clay.—Beneath the gravel, sand, and clay of recent origin lies a thick stratum of firm dense clay, containing layers of sand, pebbles, &c. This earlier rock, known as the **London clay,** forms a kind of trough under London, the edges rising to form the hills around Hampstead on the north, and around Sydenham on the south. The highest of these hills are capped with a stratum known as **Bagshot sand,** and this sand forms a prominent feature on Hampstead Heath (Fig. 227).

Tertiary rocks.—There is good reason to believe that in former times the London clay extended in a continuous layer over a large area in the south of England, and that it was covered with extensive deposits of Bagshot sand and other sedimentary materials. These strata are known as the **Eocene formation,** and form part of the so-called **Tertiary group** of rocks. Although deposited long ages ago, they are of much later date than the chalk, which is classed as a **secondary** rock; and by comparison with still more ancient rocks, such as our coal formations, classed as **primary,** they may almost be called modern. But the former large area of tertiary formations in England has been extensively removed by denudation; so that now these rocks are to be found only in a few districts—chiefly in the neighbourhood of London and the Thames estuary, and in parts of Hampshire and Dorset. Tertiary rocks are more abundant in France; and it is interesting to note that they enter largely into the formation of the Alps.

Fossils.—The various strata which make up the floor of a river basin often contain fossil remains of animals or plants, or of both, sometimes in great abundance. Some of these fossils are land and fresh-water shells, which once lived in the river and on its banks; and are, for the most part, not different from those living in the locality at the present day. A few of the shell-fish, however, have long ceased to dwell in the rivers of this country, though still found in other parts of the world.

While the shells referred to mostly represent species which are still living in Britain, it is far otherwise with the bones which are found in the same beds. Many of these bones, indeed, are those of animals extremely different from any which now inhabit this country, or are known to have inhabited it within historical times. And yet there can be no doubt that the animals which have left these remains once lived and died in Britain. Many other relics of former days are found in most sedimentary rocks, in addition to the teeth, bones, and shells which have been preserved through ages. These records are sometimes imprints or casts showing the forms of the original structures, footprints, and ripple-marks preserved in sandstone (Figs. 236, 237), or stony objects in which some inorganic substance has gradually taken the place of the original organic remains. By interpreting these writings geologists are able to determine the relative ages of rocks, and the conditions under which the sediments were deposited.

Relics of man and animals.—The fossil *fauna*, or animal population, of the south of England includes, in addition to many animals still living here, a number of extinct mammals,[1] such as the mammoth (*Elephas primigenius*); this was a kind of elephant adapted to live in a cold climate by having a thick woolly coat. Fig. 229 represents a drawing of this extinct elephant made by a contemporary artist. It was found scratched upon a piece of mammoth's tusk in the cave of La Madeleine in Central France; and it shows that man and the mammoth were living at the same time long ago in that country. Another species of elephant (*E. antiquus*) also lived in England; and along with the elephants were three distinct kinds of rhinoceros (*R. tichorhinus*, *R. megarhinus*, and *R. hemitœchus*). All these animals are extinct; but the hippo-

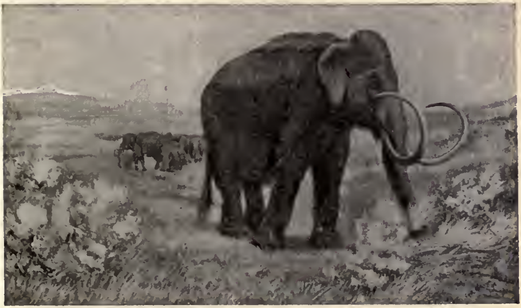


FIG. 228.—The mammoth (*Elephas primigenius*). Reproduced from a picture by Mr. C. R. Knight in the Report of the Smithsonian Institution, 1899.

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[1] *Mammals*, from Lat. *mamma*, breast; a great group of back-boned animals which suckle their young.

potamus which once lived in our country is not to be distinguished from that now dwelling in Africa. Among other animals which lived here, at the same period, may be mentioned a species of lion (*Felis spelæa*), the brown bear, the grizzly bear, the spotted hyæna, and two kinds of large wild oxen,—the bison and the urus. The gigantic Irish "elk" (*Cervus megaceros*), which is now extinct, has also left its bones in the brick-earth; and Prof. Boyd Dawkins found, at Crayford, a skull of the musk-sheep (*Ovibos moschatus*), which is a creature living at the present day only in Arctic America. Most of these are represented, not by a mere bone or two, indicating an occasional straggler, but by remains so abundant as to show that the animals which they represent were important members of the old fauna.

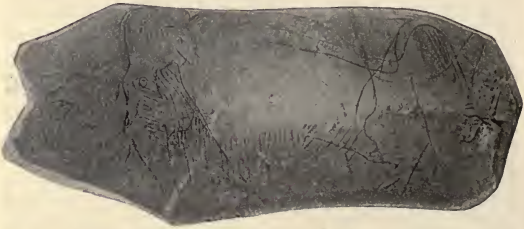

FIG. 229.—A prehistoric drawing of a mammoth, scratched upon a tusk, found in the cave of La Madeleine, Central France. Reproduced from *Reliquiæ Aquitanicæ*, by Lartet and Christy.

Cave dwellers.—Astonishing numbers of these animals have been found in the *débris* accumulated in caves in various parts of our country. For example, in a "hyæna den," a branch of the large cave known as Wookey Hole, in the Mendip Hills, Somerset, Prof. Boyd Dawkins found remains of the following animals, the numbers being reckoned from the jaws and teeth only:—

Cave hyæna	467
Cave lion	15
Cave bear	27
Grizzly bear	11
Brown bear	11
Wolf	7
Fox	8
Mammoth	30
Woolly rhinoceros	233
Rhinoceros hemitœchus	2
Horse	401
The great *Urus*[1]	16
Bison	30
The Irish elk	35
Reindeer	30
Red deer	2
Lemming[2]	1

Prof. Dawkins found the remains of these animals "so intermingled that they must have been living together at the same time." And what may be considered of peculiar interest is the fact that among them were found evidences of man, namely, the remains of fires, such as charcoal and burnt bones, and a considerable number of flint implements, the rude knives and weapons made by primitive man. (See Fig. 230.)

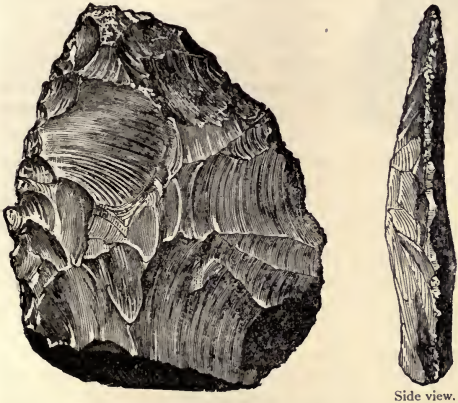
Side view.

FIG. 230.—Flint implement found in the Hyæna den at Wookey Hole, near Wells, Somerset. From *Cave Hunting*, by Prof. W. Boyd Dawkins.

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[1] A species of ox.

[2] A small rat-like rodent.

Flint implements.—The evidence of the coexistence of man with these animals is abundant in many parts of Britain. In the British Museum, there has been, for many years, a rude spear-shaped weapon in black flint, represented in Fig. 231. This was found, associated with an elephant's tooth, in an excavation near Gray's Inn Lane, London, and a description of it was published as far back as 1715. Many other flint implements have been found in the gravels in and around London. Indeed, they are so abundant in many parts of England, and also in northern France, that there is no reason to doubt the existence of man, in this part of the world, during the period at which the older river-drifts were deposited. It is probable that the early flint-using man came hither from the continent with some of the extinct mammalia, at a time when Britain was connected with the European mainland by an isthmus occupying the position of what is now the Straits of Dover.

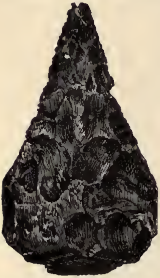
FIG. 231.—A palæolithic implement, from Gray's Inn Lane. Actual length, 6⅜ inches.

Early man.—Flint implements are the oldest known relics of man. They indicate a time, before the commencement of history in western Europe, when man was ignorant of the use of metal, and fashioned his weapons and implements out of stone. The more ancient of these prehistoric implements, such as those in Figs. 230 and 231, are simply chipped into shape; but other stone implements occur, which are neatly ground, and even polished. Fig. 232 represents a polished **stone celt**[1] which, with a part of the handle attached, was found in a peat bog in Cumberland. These more highly finished stone implements are never found in the older gravels, or along with the extinct mammalia, but are confined to the most superficial deposits. That period in which man was in the habit of using implements exclusively of stone is known to antiquaries as the **stone age**; and Lord Avebury has distinguished the early part of this period, in which unpolished stone was in use, as the **palæolithic**[1] age, and the later period, when man had advanced to the stage of grinding and polishing his weapons, as the **neolithic**[2] age. Fig. 231 represents therefore a palæolithic, and Fig. 232 a neolithic implement.

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[1] *Celts*, from Lat. *celtis*, a chisel; not, as often supposed, because they were used by the people called Celts.

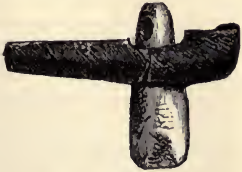

FIG. 232.—A neolithic polished stone celt, with part of the wooden handle attached. Found in a peat-bog in Cumberland. One-eighth original size linear measure.

Prehistoric times.—The study of fossils is not only of essential importance in proving the changes which have occurred in the physical geography of our country, but it brings to light other remarkable facts in its history. Animals, which now live in both colder and warmer climates than those of the south of England, are found associated together in glacial-drifts and river-gravels. But, while the great majority of these animals and plants are identical with, or very similar to, those which now live somewhere or other, the inhabitants of the world in former ages become less and less like those which now exist, as we go back in time. Thus, although in their general character the animal remains of the London clay resemble those of animals now living in hot climates, it is only a small percentage which are identical with living forms, while the rest have altogether vanished and become extinct. In the chalk, this feature is still more marked: of the many thousand beautifully preserved kinds of animal remains which have been obtained from that formation, only a very few of the lower forms are identical with species now living. Hence, notwithstanding the similarity of the chalk to the Globigerina ooze, the remains imbedded in the former at once distinguish it from the modern deposit.

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[1] *Palæolithic*, from παλαιός, *palaios*, old; λίθος, *lithos*, stone.

[2] *Neolithic*, from νέος, *neos*, new, and λίθος, *lithos*, stone.

The evidence of the rocks leaves no room for doubt that, thousands of years before the Roman occupation, the Thames valley was the haunt of savages armed with flint weapons; that elephants and rhinoceroses, bears and hyænas, roamed through its forests, and that the hippopotamus wallowed in the streams of what was, in all probability, a river of much larger dimensions than the present Thames. Arguments of similar cogency lead to the conclusion that the solid floor of the Thames basin, throughout the many hundred feet of thickness which have been directly explored, owes its origin to agents of denudation and reconstruction, such as are at work at the present day, and testifies to the general uniformity of nature throughout a period which must be counted by hundreds of thousands of years.

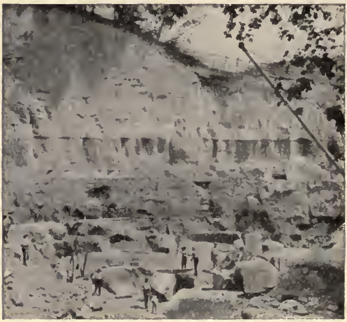

Photo. *H. W. Taunt.*

FIG. 233.—Chalk pit at Medmenham, Buckinghamshire.

A geological succession.—If a journey is taken from London in a more or less north-west direction—towards Birmingham, Worcester, or Gloucester—several folds of the strata, presenting alternately their concave and convex surfaces, will be traversed. But a moderate inspection will show that this folding is not equally balanced in all directions: for, although there are minor foldings in other directions, the strata rise on the average more towards the north-west. It will be noticed also that most of the rocks, where they reach their greatest elevation, cease suddenly, sometimes forming a bold hill-face or **escarpment** looking more or less north-westward. The cessation of each rock in this way allows a deeper and older rock-stratum to appear at the surface; and as a result older and older rocks are found to occur as the journey extends.

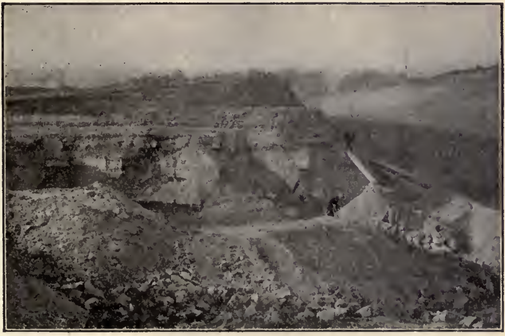

Photo. *H. W. Taunt.*

FIG. 234.—Greensand with boulders at Headington, 2½ miles below Oxford. The white streak of the Thames is seen about half an inch down from the top left-hand corner.

The hills of Middlesex are formed of London clay, which is only moderately tilted, but sufficiently so to cause the north-west faces to weather to a steeper angle than the other sides, as seen in the hills of Hampstead and Harrow.

At the Chiltern Hills the **chalk** comes to the surface and presents a long line of escarpment towards the north-west. This is very well seen from the London and North Western Railway near Cheddington station. The **greensand,** appearing from under the chalk, forms the low escarpment skirted by the railway from Bletchley toward Bedford.

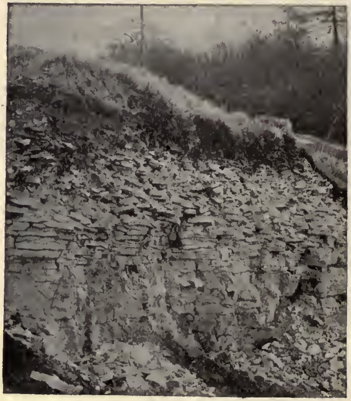

Photo. *H. W. Taunt.*

FIG. 235.—Oölite quarry near Seven Springs.

Beyond the chalk and greensand the rocks of the **Jurassic** group appear: these have weathered into softly undulating hills such as characterise the counties of Oxford and Northampton, but some of the hardest rocks of the series, known as the **oölites,** terminate in bold escarpments, as in the Edge Hills and Cotteswold Hills. The escarpment of the former is well seen from the Great Western Railway a little south of Warwick, and that of the latter forms a striking feature as seen from the neighbourhood of Cheltenham and Gloucester.

On arriving at the next series of rocks, which are known as the **Trias** or **Triassic formation,** we begin to lose that parallelism which hitherto characterises the rocks encountered in journeys from London towards the north-west. The principal rocks of this formation are the **New Red Sandstones:** they are the prevailing surface rocks over a large area of our country, and form pleasant undulating hills with a fertile soil.

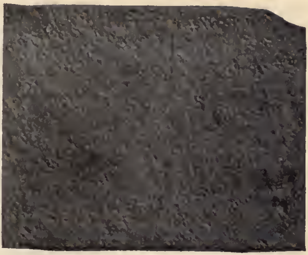

Fig. 236.—Rain-prints and reptilian foot-prints in Triassic sandstone, Turner's Falls, Mass., U.S.A. One-twelfth actual size linear measure. Photographed by Mr. J. N. Nevius, *Bulletin* of the New York State Museum, vol. iv., No. 19.

Beyond the Triassic area the arrangement of the rocks becomes more and more irregular: nevertheless the same rule holds good as at first, namely, that as we go farther west or north-west, we meet with older and older rocks, the oldest of all being found in west Wales and north-west Scotland.

Fig. 237.—Ripple-marks upon Triassic sandstone, Turner's Falls, Mass, U.S.A. One-sixteenth actual size linear measure. Photographed by Mr. J. N. Nevius, *Bulletin* of the New York State Museum, vol. iv., No. 19.

Newer and older rocks. — This arrangement of the rocks is explained as follows: since the strata around London were deposited (these being the most recent), a great change of level has taken place. The whole area of the

British Isles has been raised, but not evenly in all parts. While the neighbourhood of London has risen from below sea-level to a height exceeding Hampstead Hill, the country to the north and west has been elevated much more, causing a general average slope of the strata. But the strata which were raised highest have suffered most denudation: for example, the chalk has been more removed than the oölite, and the oölite more than the new red sandstone.

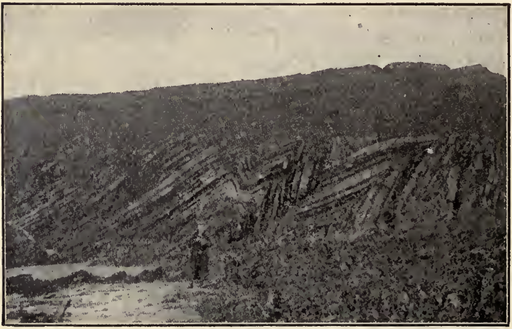

FIG. 238.—Contorted carboniferous limestone, south of Lough Shinny, co. Dublin. Reproduced, by kind permission, from a photograph by Mr. J. A. Cunningham.

All these strata formerly reached farther west, though they may not have covered the whole country. Remnants of them are found here and there, especially a considerable area of chalk in the north of Ireland. Before this upheaving took place, the older rocks had already been submitted for ages to the many crumplings to which the earth's surface is subject; and thus their foldings are more complex, and their arrangement proportionately less regular, than that of the newer rocks.

South and south-east England.—We have followed the various strata until their parallel arrangement ceases. Let us now consider the features which may be seen on a journey from London in the opposite direction, *i.e.*, towards the south or south-east. As already mentioned, the strata which lie under London are bent up on nearly all sides, forming a kind of trough. For this reason we find a repetition of several features seen in the former journey, with the difference that the strata slope in the opposite direction. At first we pass over the London clay, which forms the hills around Sydenham. Then the chalk is met, forming the North Downs, with bold escarpments facing southwards, as near Dorking. A little farther off the greensand occurs, forming the summit of Leith Hill and other principal eminences. But from this point onward the order of the strata differs from that on the north of the Thames: for from such points as Leith Hill we look southwards over the undulating district known as the Weald, in which

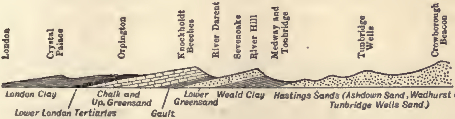

FIG. 239.—Diagrammatic section from London to Crowborough Beacon. Length, 40 miles. Heights and dips much exaggerated. (Adapted from the *Proceedings of the Geologists' Association*, 1897.)

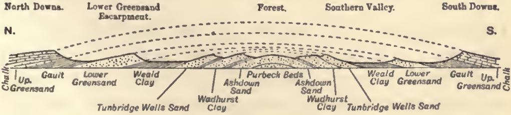

FIG. 240.—General section of the Weald and its relation to the North and South Downs. The dotted lines indicate the original strata which have been removed by denudation. (Adapted from the *Proceedings of the Geologists' Association*, 1897.)

the rocks belonging to the chalk and oölite formations have been bent into a convex or anticlinal fold, and subsequently worn down by water; so that the strata laid bare in the northern portion are found again in opposite succession as we go southwards (see Fig. 240). The southern boundary of the Weald is formed by the South Downs, a chalk range which is the antithesis to the North Downs, the strata dipping in the opposite direction, that is, to the south.

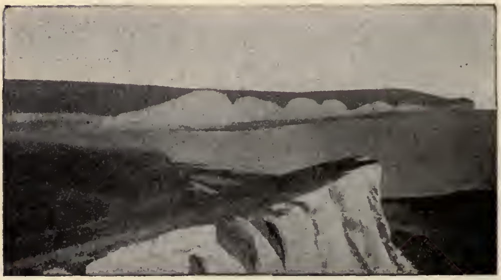

FIG. 241.—Chalk Downs and Cliffs as seen from Seaford. The point in the background is Beachy Head.

The chalk then becomes lost to view under the sea, but reappears on the opposite coast: and if the rocks of France and Belgium are examined, their succession will be found much the same as in the midland regions of England.

North and west Britain.—We left the consideration of the rocks seen on a journey north-west from London when we got as far as the New Red Sandstone group, where the strata begin to show decided irregularity of distribution. Let us now glance at some of the older or **Primary** rocks which lie farther northward and westward. These may be seen to be much less regular than the newer ones:

for the longer a rock exists, the more disturbances it may be subjected to. They are also harder as a rule than the newer rocks, which again is a result of age, as will be presently explained: and these two characters, hardness and irregularity, cause the scenery of the north and west of Britain to be generally more rugged than that of the south and east. From the many varieties of primary rocks we will select a very few types, in order to consider their influence on the aspect of the country.

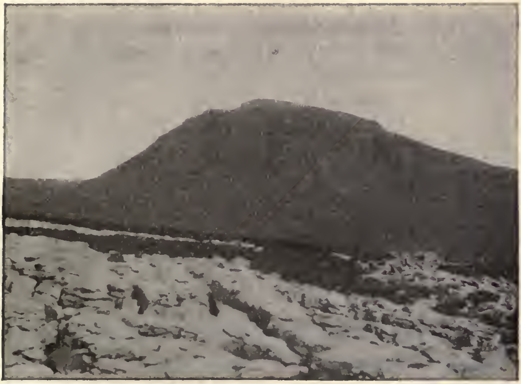

Photo. *Godfrey Bingley.*

FIG. 242.—Ingleborough, Yorks., from Raven Scar. The summit of the mountain consists of Millstone Grit and the base of carboniferous limestone. The hard cap has protected the rocks under it, while the surrounding parts have been worn away.

All the coal-deposits of any importance in Britain occur in the group of primary rocks named **Carboniferous**,[1] though in some parts of the world coal occurs freely in rocks of later formation.

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[1] From Latin, *carbo*, coal, and *fero*, I bear.

The primary **limestones** are hard rocks which weather into bold picturesque cliffs. The most conspicuous of these limestones in Britain is the **Carboniferous limestone.** This rock lies beneath the coal in our coal-fields; but in some of our mountain districts it has been raised into such a prominent position that it is equally well known by the name "mountain" limestone. Its rugged cliffs contribute much to the fine scenery of West Yorkshire and Derbyshire, where it is capped in places with hard **Millstone Grit** (Figs. 242, 243), the Wye (Fig. 244), the Bristol Avon, and the Mendip Hills (see Fig. 80); also Killarney and other beautiful spots in Ireland.

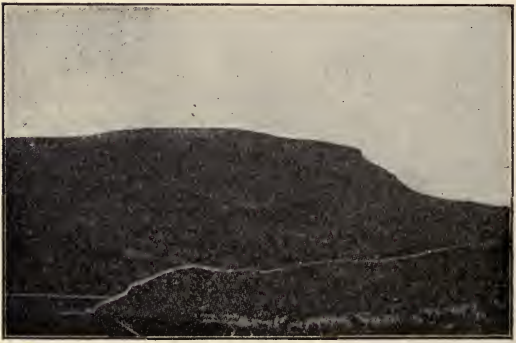

Photo. *Godfrey Bingley.*

FIG. 243.—Penyghent, Yorks. Millstone Grit upon a platform of carboniferous limestone. A relict mountain produced by the denudation of the surrounding country.

Sandstones are of frequent occurrence among the primary rocks. Of these the **Old Red Sandstone** is the most extensively developed. It forms the finest scenery of South Wales (*e.g.* the Brecon Tors), is an attractive feature in

Herefordshire and Shropshire, and covers a large area in the Scotch Lowlands, and again in the extreme north of Scotland.

In the Scotch Highlands, the mountains of Wales and Ireland, and the south-west peninsula of England, the prevailing rocks are of the **metamorphic** class, *i.e.* such as have been profoundly altered in structure in the course of ages. They include **slate** and various rocks of a more or less crystalline structure.

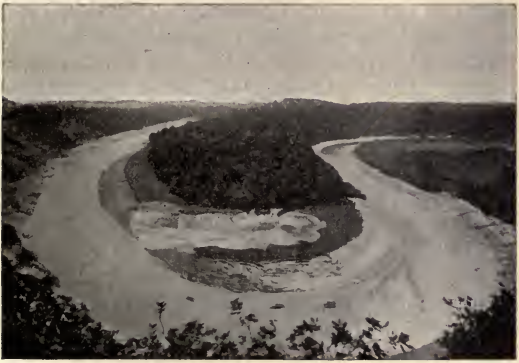

Photo. *F. Frith and Co.*

FIG. 244.—Mountain limestone scenery: bend of the River Wye, near Chepstow.

Altered rocks.—The effects of time on rocks are evident in more ways than one. The most evident effect is the displacement, crumpling, and crushing which results from the earth-movements: but meanwhile other changes are going on continually, which affect the density and the chemical composition of rocks. If the rocks of different ages are compared, the older will be found to be denser on the average than the newer. This is seen in the difference between the very hard **Old Red Sandstone** and the friable **New Red Sandstone**: or, if three great formations of limestone—the chalk, the oölite, and the carboniferous—are compared, it will be found that the first can be cut with a knife, the second with a saw, while the third is so hard as to be shaped usually by chipping and grinding.

After making all due allowance for difference in the hardness of the rocks when first deposited, it is still evident that many of them owe their present hardness to changes which have taken place subsequently. One cause of such changes is the percolation of water, which dissolves some of the softer parts and removes them. Water also partially dissolves the materials when the temperature rises, and precipitates them when the temperature falls, the precipitated material cementing the undissolved particles together. But pressure and heat also tend to consolidate rocks. When newer strata are deposited to a thickness of thousands of feet on the top of the old, the pressure becomes enormous. We know, too, that the deeper parts of the earth's crust are hotter than the surface. Thus deep-lying rocks are subject to three agencies, namely, great pressure, high temperature, and percolation of water, all of which have a hardening and consolidating effect, and a tendency to alter the chemical composition of a rock.

A remarkable change of internal structure under pressure is seen in **slate**, which is produced from clay when enormous **lateral pressure** acts upon it for a very long period. The clay gives way to the stress, and its particles are thereby forced into a new position, being all compelled to lie in parallel planes facing the direction of the pressure; and on this parallel arrangement the splitting of slate depends.

Another effect of pressure, heat, and water is repeated crushing, and re-cementing of the fragments; so that the rock acquires a crystalline structure, while the signs of original stratification are rendered indistinct and the fossils obliterated. These results are well seen in the mountain districts just mentioned, where the most ancient rocks have been folded, crushed, and folded again in a manner almost incredible to any one who has not investigated the matter closely.

Fused rock.—Under extreme crushing or friction rocks are actually raised to the melting temperature, and may thus lose all signs of their sedimentary origin. Below or beyond all the rocks of evident sedimentary origin, rocks are found the structure and chemical composition of which show that they have been formed by fusion, whence they are named **igneous**[1] **rocks.** Probably some of these were originally sedimentary, but have undergone metamorphosis and fusion as above described: others may have been expelled from deeper regions by volcanic action. In many cases the igneous rocks have intruded into gaps and fissures

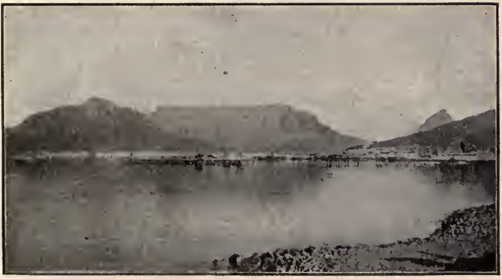

FIG. 245.—Table Mountain, Cape Colony, consisting of tabular sandstone masses resting on slate and schists, and penetrated in many places by granite dykes. From a photograph.

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[1] From Latin, *ignis*, fire.

in the overlying strata; and in this way they have generally filled the arches or tunnels which are formed at the anticlinals or convex portions of bending rocks.

When these melted rocks escape at the surface, they form lava and other volcanic rocks: but when they remain at a great depth, they cool so slowly that their constituent substances have time to crystallise very completely; and thus they form the crystalline rocks of which **granite** is a type.

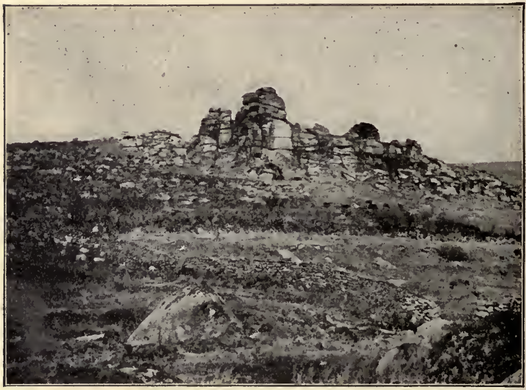

FIG. 246.—Pu Tor, Dartmoor: wall-like weathering of granite. Compare the real wall in the foreground with the granite blocks in the background. From a photograph by Mr. W. Jerome Harrison.

Wherever highly crystalline igneous rocks are exposed at the surface, as in the Highlands, or Dartmoor (Devon), the Malvern Hills (Worcestershire), or Charnwood Forest (Leicestershire), evidence is found that these rocks were formerly covered by thousands of feet of overlying strata, under which they cooled slowly after melting. These granitic rocks were formerly in the heart of lofty mountains, which have been reduced to their present moderate height by denudation (Figs. 246, 247).

Life-history of a rock.—From the foregoing considerations it appears that mud deposited in a sea, lake, or river may undergo a series of mechanical, thermal, and chemical changes; and that as a result of these changes it may in the course of long ages be converted successively into soft rock, hard rock, metamorphic rock, and igneous rock. It must be remembered, however, that this is not the history of every rock: only those which become depressed and heavily overlaid will suffer the later changes.

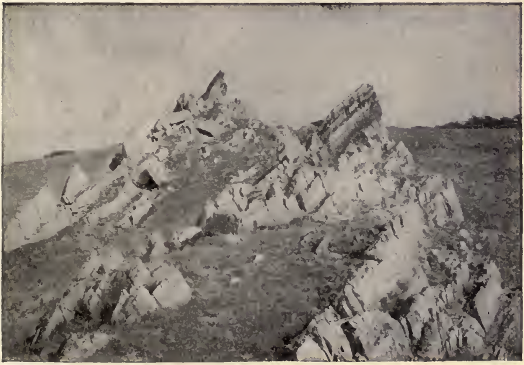

FIG. 247.—Broombriggs, Charnwood Forest: crags of hardened igneous rocks from which the overlying strata have been removed by denudation. From a photograph by Mr. W. Jerome Harrison.

Effects of change of level.—It is remarkable how the chemical constituents of different strata differ from each other—how at one period limestone has been formed, at another time sandstone, or clay, or what not. The reason for the differences of rocks is to be sought chiefly in the changes of level: these may cause the same locality to be at different times a sea-bottom, a lake, a marsh, or dry land; and each of these conditions favours the accumulation of some particular kind of deposit, as explained in Chapters VIII and XI. A change of level is also liable to cause material to be received from a different district, and therefore to contain different substances. So, when two parallel strata are found differing widely in chemical composition, we may usually surmise that a change in the relative altitude of the locality took place between the periods when the two strata were deposited.

Before leaving the subject of the formation of the rocks, it may be well to mention that there is no place on earth where all the rocks, from oldest to newest, exist in uninterrupted succession: but by comparing the strata in different localities a fairly correct idea can be formed of the order of their deposition.

Internal heat.—So far we have dealt only with the crust of the earth, that is, the part of the earth's exterior which can be investigated. But though the interior is beyond our reach, some idea of its state can be formed by means of inference.

For instance, it is known that the specific gravity of the earth as a whole is 5·5;[1] while that of the average rocks at the surface is only 2·5 to 3, or about half as great. It follows, therefore, that the interior must be of much higher specific gravity than the crust. Then, it is known that the interior is very hot, and that the materials which exist there may be above their melting temperature, though perhaps kept solid by the great weight of overlying matter, except where hollows, fissures, or gaps in the crust give opportunities for escape from pressure. The high specific gravity of the interior is attributable to two causes; namely, the tendency of the densest constituents to fall towards the centre, and the compression of the deeper parts by the more superficial. The cause of the internal heat is to be sought in the history of the origin of the world and the solar system.

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[1] *i.e.* 5·5 times heavier than water.

Formation of worlds.—There are many reasons for believing that our sun, and its attendant planets, of which the earth is one, originated by the gradual condensation of a mass of attenuated material such as is seen in a **nebula.**[1] The telescope has revealed many masses of luminous haze—nebulæ—of various forms, existing in starry space (Fig. 248). A nebula was at one time supposed to be merely a cluster of stars so far away that their rays were merged together; and it was believed that if a telescope of sufficient power could be obtained the individual stars would be seen. Observations with the spectroscope have proved, however, that the light of a nebula has a quality of its own which distinguishes it from starlight in general. There are a few stars with nebulous material around them, but these represent a transition stage between a formless mass of celestial mist and a luminous globe such as the sun. A nebula appears to represent the material

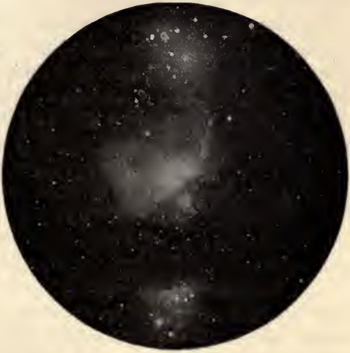

FIG. 248.—The great nebula of Orion. From a photograph by Dr. Isaac Roberts, F.R.S.

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[1] Latin, *nebula*, fog, mist.

which is fashioned into worlds in the course of ages. In no one case can this development be traced, but several lines of research have shown that the finished stars and the nebulæ are connected by such intermediate steps as to make it highly probable that every succeeding state of the nebulous matter is the result of the action of gravitation upon it while in the preceding one.

Evidence is in favour of nebulæ being vast clouds of cosmic dust and fragments of solid matter, all in whirling motion. Collision and friction between the solid particles produce sufficient heat to drive off occluded gases and render them luminous; but so long as the material of the nebula is sparsely distributed, the light and heat escape by radiation, and so the matter remains at a low temperature. The whirling motion will tend to resolve into a vortex-like revolution of the whole nebula round the centre of gravity, while smaller vortices will occur here and there. Friction and collision cause slowing of motion, and allow the material to gravitate towards the centres of the vortices. In this way the principal vortex resolves itself into a sun, and the minor vortices become secondary suns or planets, with satellites formed from the smallest vortices.

Cooling globes.—When the material of a nebula condenses into compact masses, the heat produced by collision and compression accumulates in the interior of the masses, but escapes more or less from their surfaces. Since the mass of a sphere varies with the cube of the diameter, while the surface varies with the square of the same, it follows that as a sphere grows larger the ratio of radiating surface to the mass diminishes; and as the surface is the part whence heat escapes, the loss of heat is proportionally slower in a large sphere than a small one. Thus a world formed from a larger vortex will retain its heat longer than its smaller companions, and will be hotter in every part, whether at the centre or at the surface.

A world so large as the sun produces heat enough internally—chiefly, it is believed, as a result of its continual contraction, whereby the energy of gravitation is converted into the energy of heat, light, &c.—to keep its surface white-hot in spite of loss by radiation. The planet Jupiter, which is much larger than the earth, can keep its surface perhaps barely red-hot; but a small mass like our earth can produce so little heat, in ratio to the loss by radiation, that the surface is comparatively cool.

From the study of the fossils in our rocks, it appears that all the animals and plants, of which they are the remnants, were of such a character as to require similar temperatures to those which prevail at the present time on the earth. So it seems that the earth's crust has been at about the same temperature for countless ages, no doubt for millions of years, though the interior has been very hot. The surface would have been intensely cold, except for the heat received from the sun, which has nearly counterbalanced the loss by radiation.

But the balance is not perfect: some of the central heat is always being conducted towards the surface and slowly dispersed, especially from the polar regions. This loss of heat from the interior must be attended by contraction, and so the interior of the earth is always shrinking; while the crust remains at a nearly constant temperature, and therefore hardly changes in size. It has already been explained in Chapter XI how this gives rise to folding movements of the crust. Though the evidences concerning the origin of the solar system, and the formation of the earth's interior, are of a much less tangible kind than those of changes going on at the earth's surface, all known facts tend to indicate that the history of the earth was from the first, as it is at the present time, a history of continuous evolution under the operation of natural causes.

CHAPTER XVIII

FIGURE OF THE EARTH

Circumnavigation.—One's earliest and most natural impression is that the surfaces of the land and sea are everywhere flat, if local elevations are left out of consideration; and, for many ages, it was the accepted belief of mankind that the land was a huge flat cake surrounded on all sides by an illimitable ocean. But when, in 1520, Magellan, sailing westward from Europe, passed round the southern end of South America; and, his ships keeping their bows continually in the same direction, eventually reached the coasts of Asia, and thence returned to the place from whence they set out, it was concluded that, at any rate along the track he followed, the surface of the earth was round. Since then the earth has been circumnavigated many times and in various directions; and though this does not prove the world to be round, as is sometimes suggested, it shows that the surface on which we live is not a vast plane of land and water.

Appearances due to curvature.—Very simple observations afford proof that the surface of the earth is curved, not only in one direction but in all directions; or, in other words, that it has the shape of a ball.

One of the most commonly cited, but at the same time one of the most convincing, proofs of this curvature is based upon a simple observation which any one can make for himself at the sea-side. If a ship be watched, as she leaves the coast, it will of course be seen that she gets smaller in size and fainter in outline the farther she stands out to sea. But, in addition to this change of size and of distinctness, the figure of the ship suffers a change. In fact, the hull of the vessel seems gradually to sink into the sea, and at length disappears altogether. Yet it might fairly be supposed that the hull, being the largest part, would remain longest in view. After the hull has passed out of sight, the funnel or the lower sails, in like manner, are lost to view; then, the upper gear appears to dip beneath the water; and, at last, only the tops of the masts are to be seen peeping above sea-level, or, in the case of a steamer, the smoke from the funnel can be seen. A telescope may make so much as is to be seen of the ship more distinct; but, it will not bring the lower part again into view, after it has once been lost. There seems to be no way of explaining this observation of a vessel sinking out of sight on the supposition that the earth is a flat plane; but the explanation becomes easy enough, if it be admitted that the surface is slightly convex (Fig. 249).

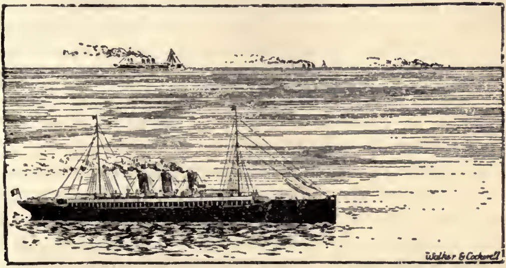

FIG. 249.—Effect produced by curvature of the sea surface.

To the sailor who is approaching land, similar appearances are presented; the first points which are visible to him are the peaks of hills, or the tops of buildings. He is prevented from seeing the bases of these objects by the water which is between him and the shore. Now, as these appearances are not confined to any one locality, but are seen in every part of the world, it follows that the earth must have a general curvature. In fact, it can be shown that the convexity is everywhere very nearly the same; and it is, therefore, clear that the earth is a globe-shaped body.

Points of view.—It is possible to obtain similar proof of the earth's roundness by observing a vessel which is stationary. Suppose that a person, who is about to bathe in a calm sea, sees a small boat a mile or two from shore. Let him then get into the water, and, with his eye only a few inches above sea-level, look along the surface of the water in the direction of the boat. He will now find that the boat is more or less hidden, or perhaps altogether lost from sight. In fact the curved surface of the sea obstructs the view; and the obstruction is greater, the lower the position of the bather's eye. When a man is standing on shore, his eyes are raised something like five feet above ground; but, when he stands with the water up to his chin, they are only a few inches above the sea-level, and his view is accordingly obstructed. When the observer is in an elevated position, he is able to look over the low hill of water which interferes with the prospect at lower levels: hence, more of a distant ship can be seen from the top of a tower than from its base.

Distance of the horizon.—If a person standing on the deck of a ship at sea or a wide plain, with nothing to obstruct his view, looks round about him, he finds that the boundary of his vision extends equally in all directions, and thus forms a circle. This boundary is called the **apparent** or **visible horizon**.[1] The term horizon, at least as used in this sense, therefore denotes the circle of vision which seems to separate the sky from the earth on land, or the sky from the water on sea. It is the outline which limits a person's outward view, wherever he may happen to be. But, if the observer mounts a hill, or ascends a tower, or climbs to the mast-head of a ship, he finds that his circle of vision becomes extended, and he can see objects which were before beyond his range; in other words, his horizon increases, or becomes a larger circle. This is illustrated by Fig. 250. A person standing at the foot of the mountain has his view limited by the small circle; if he goes half-way up the mountain, his horizon expands to the middle circle, and, if he goes quite to the top, it enlarges to the outermost circle. If a man's eyes are five feet above ground, as they might be if he stood at the base of the hill, the radius of his horizon will be less than two miles and three-quarters; but, if he went to the top of Eddystone Lighthouse, his horizon would then have a radius of more than fifteen miles.

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[1] *Horizon*, from ὁρίζω, *horizo*, to bound or limit.

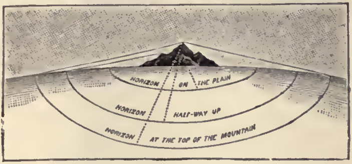

FIG. 250.—Variation of distance of horizon with the altitude of the observer.

Since it is found that the horizon is invariably circular in every part of the world, it is proved that the earth must be spherical; for a sphere is the only kind of solid which presents a circular contour from whatever point it is viewed.

Terrestrial and celestial spheres.—Other means of demonstrating that the surface of the earth is rounded, and not flat, may be obtained from observations of some of the heavenly bodies. One interesting mode of proof may be explained by the help of Fig. 251. Here the earth is represented as hanging in the centre of a great space, which is bounded on all sides by a starry vault. The point in the heavens which an observer sees directly overhead, when he looks up, is called the **zenith**; and the opposite point, which is immediately beneath his feet, and is therefore impossible for him to see, since the solid earth stands in his way, is called the **nadir.**[1] The direction of the straight line joining these two points is the direction in which a plumb-line hangs when the plummet is free.

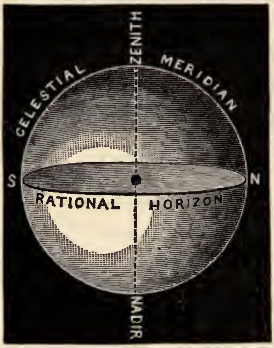

Fig. 251.—The earth within the celestial sphere.

The great plane which is shown in Fig. 251 passing through the centre of the earth, and extended to the celestial sphere, is distinguished as the plane of the **true, or rational, horizon,** which is an imaginary circle dividing that sphere into two equal halves, one above and one below the true horizon.

Altitude of the pole star.—It was explained on p. 5 that very near to the north pole of the heavens there is a star called the pole star. That point on the horizon which is exactly under the north celestial pole is the true north, and the other cardinal points on the earth's surface are also referred to the horizon. Now, suppose a person measures the angle between the pole star and the north point of the horizon (Fig. 252); and that two persons travel from this place of observation—one going due north, and the other due south—and that they observe, at different times, the apparent altitude of the same star, or its height above their horizon. To the man who travels northwards, the pole star will appear to mount higher and higher in the heavens; and, if the ice in the arctic regions did not prevent him from getting so far, he would eventually find this star over his head. In fact, it will be seen from Fig. 253 that the pole star is in the zenith of an observer at the north pole. But, to the person who travelled southwards, the pole star would appear to be steadily sinking lower and lower in the sky; and, when he got midway between the north and south poles of the earth, at the line called the **equator**, he would find that the star actually seemed to touch the horizon; while, if he continued his course to the south, it would disappear altogether. But the person who stayed at home would not have observed any movement in the position of the star. In fact, it does not sensibly change its place; and the difference observed in the altitude of the star by the travellers has been due to their own change of position on the earth's rounded surface, as shown in the figure. This, therefore, proves that the earth is convex, at least in a north-and-south direction.

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[1] *Nadir* and *zenith* are words of Arabic origin.

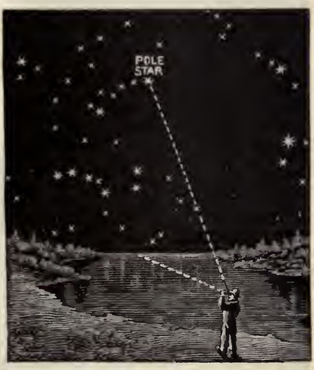


FIG. 252.—Measurement of the altitude of the Pole Star. This altitude is approximately equal to the latitude of the place of observation.

If the travellers, instead of going northwards and southwards, had taken their journey due east and due west, they would not have observed any alteration in the altitude of the pole star. But, by referring to his watch, the traveller to the east would have found that the sun rose earlier and set earlier than it did when he was at home; while the traveller to the west would have found that it rose later and set later. It can be shown that this is a proof of curvature in an east-and-west direction; and, therefore, by combining the two sets of observations the rounded shape of the earth's surface may be fully established.

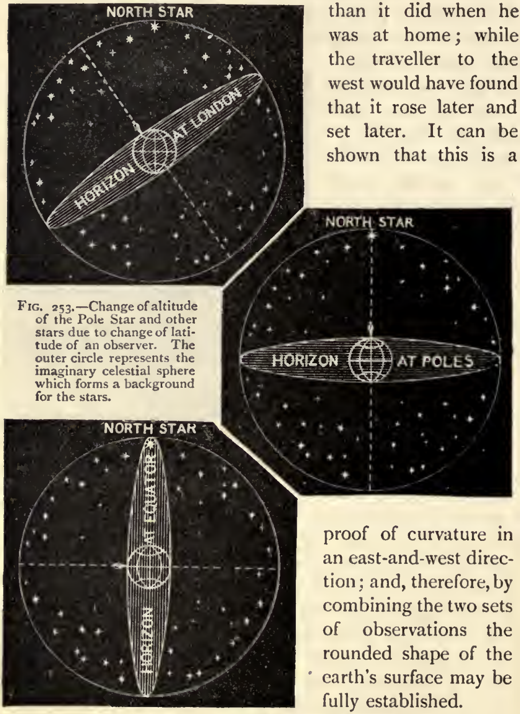


FIG. 253.—Change of altitude of the Pole Star and other stars due to change of latitude of an observer. The outer circle represents the imaginary celestial sphere which forms a background for the stars.

Curvature of water surface.—Engineers and surveyors are in the habit of taking the earth's sphericity into account in their calculations. If, for example, a long canal has to be cut, an allowance must be made for curvature in order that the depth of water in the canal may be the same throughout. A convincing experiment to prove the rotundity of the earth was made by Dr. A. R. Wallace, in 1870, in the Bedford Level, which is a portion of the Fens north of Ely, and presents long, straight channels of water without current or tide. Three signals, each thirteen feet four inches above water-level, were erected at distances of three miles apart. On looking through a telescope, adjusted in such a manner that the line of sight touched the tops of the first and last poles, it was found that the middle signal was upwards of five feet above the line. This rise was of course due to the convexity of the earth's surface. Mr. H. Yule Oldham repeated the experiment in 1900 and 1901 on a six-mile stretch of water between Welney and Denver. The middle mark in this case was found to stand up about six feet above the line of sight, agreeing with the effect calculated to be produced by the curvature of the earth's surface.

Oblateness of the earth.—Such evidence as that which has been adduced in this chapter, proves conclusively that the earth has a curved surface, and that the curvature is roughly that of a globular body. Very delicate operations have enabled men to determine the figure of the earth with the greatest accuracy, and have shown that this figure is not exactly that of a true sphere.

In a perfect globe, every diameter or line drawn from surface to surface through the centre has the same length, and if the globe is cut into halves, the boundary of each half is a circle. Observations show that the earth does not satisfy these conditions. A progressive diminution of curvature is found in passing from the equator northwards, and in the neighbourhood of the north pole a decided flattening occurs. A girdle placed round the earth so as to pass through the poles would therefore not be perfectly circular. Only one straight line—the **polar diameter**—can pass from pole to pole through the earth's centre, and it is found to measure 7,900 miles (Fig. 254). An **equatorial diameter** of the earth is a line which passes through the earth's centre from point to point in the equator; and accurate measurements show that its length is not the same in all directions, hence the equatorial circumference is not exactly a circle, but is slightly elliptical; its longer diameter measuring about two miles more than its shorter diameter. The average equatorial diameter is about 7,926 miles: in other words, the equatorial exceeds the polar diameter by about twenty-six miles. The proportion of twenty-six miles to 7,926 miles is very nearly that of 1 to 300, and hence the earth is said to have an **oblateness** of $\frac{1}{300}$.

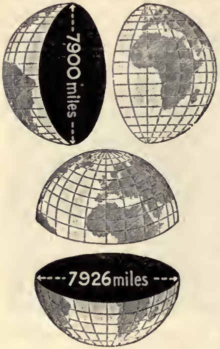
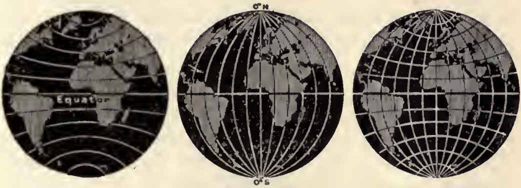


FIG. 254.—Polar and equatorial diameters of the earth.

These variations from the shape of a true sphere are so extremely slight, in comparison with the great magnitude of the earth, that, speaking roughly, the earth may for practical purposes be called a sphere; and it may be regarded as having the shape represented by our ordinary globes. In fact, the departure from the spherical shape is too slight to affect a model of this kind, unless it is of unusual magnitude. In a globe 2 ft. 6 in. in diameter, for example, the difference of the polar and equatorial diameters would be about one-tenth of an inch. It is evident, therefore, that the popular comparison of the shape of the earth with that of an orange conveys an exaggerated idea of the amount of polar flattening. Moreover, there is reason to believe that though the earth is flattened in north polar regions, the land of the Antarctic Continent is elevated rather than depressed.

Determination of position.—In order to represent any country by drawing its outline upon a globe, or upon a map, it is necessary in the first place to have some means of fixing the position of places upon the surface of the earth. When geographers wish to mark the place of any point, they refer it to certain fixed lines which they imagine to be drawn upon the surface of the globe. They proceed on the convenient fiction that a line is traced entirely round the earth, midway between the two poles; and this line, which is practically a circle, they call the **equator**[1] (Fig. 255). The equator consequently divides the world into two equal halves—a northern hemisphere and a southern hemisphere. It is further supposed that each of these halves is banded round by a number of circles, which run parallel to the equator, but get smaller and smaller on approaching the poles. These circles are called **small circles**, while the equator is called a **great circle**. The centre of a great circle must be the centre of the sphere on which the circle is drawn; and it is plain that if the earth



CIRCLES OF LATITUDE.

MERIDIANS OF LONGITUDE.

LATITUDE AND LONGITUDE.

FIG. 255.—Parallels of latitude and meridians of longitude separated and combined.

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[1] *Equator*, from Lat., *æquo*, to make equal.

were to be cut through at the equator by a flat plane, this plane must pass through the earth's centre: but planes passing through any of the small circles, parallel to the equator, would not pass through this central point.

Angular measurement and latitude.—The equator is a standard line from which distances north or south may be measured. Every circle is divided, for convenience of calculation, into 360 equal parts, called **degrees**; and it is supposed that the circumference of the earth is divided in this way. The distance of any place from the equator, measured along a circle which passes through the poles, and expressed in degrees, is called the **latitude**[1] of that place. The distance from the equator to the north pole is one-fourth of the earth's circumference, and therefore the latitude of the pole is said to be 90°, or one-fourth of 360° measured from the equator northwards. In like manner, the south pole is in 90° south latitude. Each **degree** of latitude is divided into 60 equal parts called **minutes**, and each minute into 60 equal parts called **seconds**. Degrees are represented by the symbol °, minutes by ′, and seconds by ″. A minute of latitude is a geographical or **nautical mile**, and its length is 6,080 ft., or 1·151 statute miles. The speed of a ship is stated in knots, that is, nautical miles per hour.

Longitude.—Latitude alone could never fix the position of a place. Any number of places, for example, might be situated, like London, in latitude 51° 30′ N., that is, on the circle which runs round the northern hemisphere at $51\frac{1}{2}°$ from the equator. Two sets of standard lines are needed to determine the position of a point on a surface. Geographers have consequently been led to draw a number of imaginary circles round the globe, all running through the north and south poles, as in Fig. 255. These are called lines of **longitude**, and they differ in several respects, besides that of direction, from lines of latitude. All lines of longitude form circles which have the earth's centre as their centre; in other words, they are all great circles. But all the lines of latitude, except the equator, are small circles. Again, the lines of latitude form equidistant circles, and are hence commonly called **parallels of latitude**. But no one can speak of "parallels of longitude," because these lines are not parallel, inasmuch as they all meet together and cross at each of the poles. It is common, however, to refer to these imaginary north and south circles as **meridians**, for the reason pointed out on p. 4.

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[1] *Latitude*, from Lat., *latitudo*, breadth.

Parallels and meridians.—While latitude is always measured from the equator, longitude has no natural starting-line. The reckoning may begin indeed from any meridian, and different countries actually use different lines for this purpose. The meridian from which the reckoning begins is called the **first, or prime meridian**; and, in this country, it is the meridian which passes through the observatory at Greenwich. Greenwich, therefore, has no longitude; and, in like manner, all places due north and south of Greenwich have no longitude, since they are on the same meridian. But all places to the east, or to the west, of this first meridian have their longitude, which is expressed in so many degrees, or minutes, or seconds, and is designated as east or as west, according to their position with reference to Greenwich. As the equator is divided into 360 degrees, it may be supposed that a meridian passes through each of the 360 divisions. Hence a degree of longitude, measured at the equator, is the $\frac{1}{360}$th part of the circumference of the earth. But in going to the north, or to the south, of the equator, the meridians draw closer and closer together until they meet at the poles, as shown in Fig. 256. Each parallel of latitude, whether large or small, is divided, like the equator, into 360°; and, therefore, the length of a degree of longitude gets less and less in passing from the equator, where it measures 60 geographical miles, to either of the poles, where it vanishes altogether. The reckoning of longitude proceeds from the first meridian to the east and to the west, until the figures reach 180°; the reckoning of latitude proceeds from the equator to the

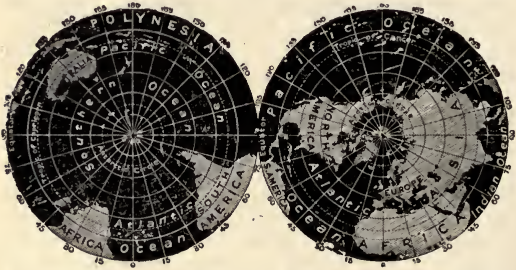


FIG. 256.—Southern and northern hemispheres of the earth, showing the decreasing distance between two successive lines of longitude measured on a circle of latitude.

north and to the south, until the figures reach 90°. Hence no place can have a greater latitude than 90°, or a greater longitude than 180°.

It would be too long a story to explain how latitude and longitude are practically determined. Unless people happen to be mariners, or surveyors, or travellers, they never have occasion to fix their position by these means. But every one is concerned more or less with latitude and longitude, for it is by means of these co-ordinates that we can find out any given place upon a map or a globe. The cross-lines of latitude and longitude form, indeed, a framework on which the geographer traces the outlines which show the distribution of land and water upon the surface of the earth.

CHAPTER XIX

THE MOVEMENTS OF THE EARTH

Restless nature.—It has been shown in the preceding pages that the waters of the earth are in a state of constant circulation; that the atmosphere is never in repose; that the solid materials of the earth's crust are slowly but incessantly changing their position; and that the matter of the organic world is subject, in a yet more marked degree, to cyclical changes. Absolute repose is, indeed, a state utterly unknown upon the earth's surface. Nor is the globe itself exempt from movements which are of a still grander kind. The huge ball which was described in the last chapter is constantly in motion. Part of this motion is a movement of **rotation**, whereby the earth is perpetually spinning round like a top; and part is a movement of **revolution**, whereby it progresses through space, and is carried round the sun.

Day and night.—If the earth were fixed in space, without either of these motions, it is plain that the half which happened to be turned towards the sun would enjoy uninterrupted sunshine, while the opposite half would be plunged in permanent shadow; in other words, perpetual day would reign in one half, and perpetual night in the other half (Fig. 257). The illuminated hemisphere on which the sun's rays were constantly shining would of course become intensely hot; while in the absence of an atmosphere the darkened hemisphere would become intensely cold, by the unchecked radiation of its heat into space. Under such conditions, the hottest part of the world would be the middle of the sun-facing hemisphere, because the solar rays would there fall square upon its surface; while the heat would diminish in all directions towards the circumference, because the rays would be received in a more slanting direction on those parts which were farther from the centre of the lit-up half.

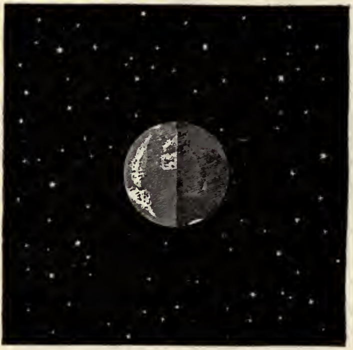


Fig. 257.—If the earth did not rotate, one hemisphere would be in continual sunshine, and the other would have perpetual darkness.

The alternation of day and night shows that these conditions of light and darkness, warmth and cold, do not exist in reality. Every part of the earth receives the sun's rays at some time or other during the year, and at all places in the great belt between the Arctic and Antarctic circles there is sunlight for several hours every day. When it is mid-day in England, it is midnight in New Zealand; but twelve hours later the conditions are reversed, and our part of the world is in darkness while the regions on the other side are being lit up by sunbeams (Fig. 258).

Day thus follows night, and night the day, in each hemisphere. Every morning the sun appears to rise above the eastern horizon, and, after sweeping across the sky in a curved path, to set towards the west. Every night many of the stars appear to rise and set in the same manner; and when the moon is visible it also can be seen to follow a track like that apparently traced by the sun in the sky. The apparent diurnal movements of these bodies from east to west are known on independent grounds to be due to the rotation of the earth upon its axis from west to east.

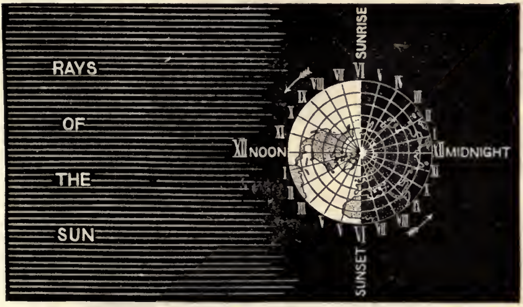


FIG. 258.—As the earth rotates, each place is brought under the hour shown by the clock figures.

Rotation of the earth.—Every one must have noticed in travelling by railway that if his own train is in a station, alongside of another, he constantly fancies the other train is moving, when it is his own which has gently started; and, on looking out of the window, when the train is at speed, it may be really difficult to persuade one's self that the telegraph posts, and the nearer trees and houses, are not whirling past the more distant objects in a direction contrary to that in which the train is moving. And although, when one looks at the rising or the setting sun, it seems contrary to the evidence of one's senses that the sun is not moving and the earth is, yet this is one of the many cases in which what is called the direct evidence of the senses is nothing but a hypothetical interpretation of the facts of which sensation tells us. That this apparently obvious and natural interpretation of the fact of the change of place of the sun and stars—an interpretation upon which the whole human race were agreed a few centuries ago—is wrong, and that it is the earth which rotates, has long been rendered highly probable; and an experiment devised by M. Foucault in 1851, and since repeated many times, completed the proof.

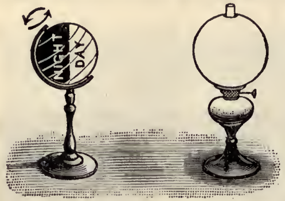
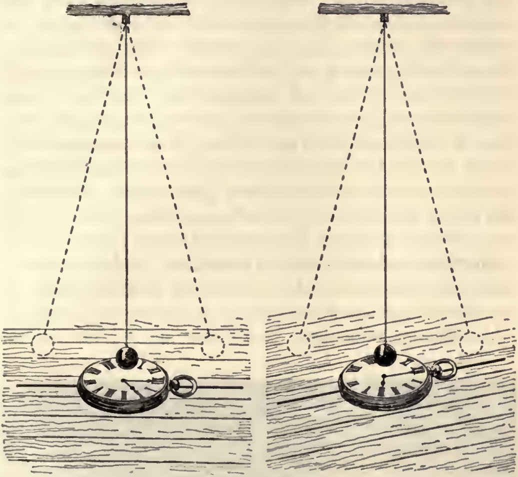


FIG. 259.—Experimental illustration of the cause of day and night.

Proofs of the earth's rotation.—The success of **Foucault's pendulum** experiment depends upon the fact that when any object is set in motion in a certain direction, it preserves that state of motion unaltered until forced to move otherwise by external action. A heavy ball is suspended by a long wire from the ceiling of a high building, and is then set swinging to and fro in a certain direction marked upon the ground or other surface under it (Fig. 260). In a short time the line indicating the direction in which the oscillation was started is found to be no longer under the pendulum; and in the northern hemisphere the twist of the original line with reference to the pendulum is always in the opposite direction to that in which the hands of a watch move when placed on the ground face upwards. To a casual observer it would seem that the pendulum had changed its position of swing; but this cannot be the case, because no additional force is brought into play to cause any deviation from the original direction. The true explanation is that the ground under the pendulum is carried round on account of the rotation of the earth, while the pendulum itself preserves its own direction of motion in the air. The experiment thus provides a direct proof that the earth is actually spinning on its axis.



Walker and Cockerell.

FIG. 260.—Proof of the rotation of the earth. The pendulum is started swinging over a line on the floor or a table. After a time, the line is found to have turned under the pendulum in the opposite direction to that in which the hands of a watch move. (Diagrammatic representation: the pendulum should be from 50 to 100 ft. long.)

As all parts of the earth are carried round the axis in the same time, the actual velocity of movement of a point in any latitude depends upon its distance from the axis. The top of a tower must move with greater speed than the base, and the mouth of a mine shaft, being farther from the axis than the bottom, must have a higher velocity. An experimental proof of the earth's rotation based upon this fact was proposed by Newton, and has been carried out at several places. Balls have been dropped from great heights, and instead of falling exactly under the point from which they were let go, they fell a little eastward of it. If the earth were at rest, the balls would have fallen vertically down in the direction of a plumb-line; and the decided deviation to the east shows that the earth rotates from west to east. When the balls are dropped, their eastward velocity is the same as that of the point from which they are set free, but the eastward velocity of the ground upon which they fall is less, consequently the balls touch the ground a little to the east of a vertical line from the higher point

Surface velocity due to rotation.—Since the earth's figure is nearly spherical, it follows that different points on the earth's surface must move, during the daily rotation, with different velocities. Any point on the line of the equator will describe a circle equal to the circumference of the earth. The earth's circumference is nearly 25,000 miles; and, as the rotation is effected in nearly twenty-four

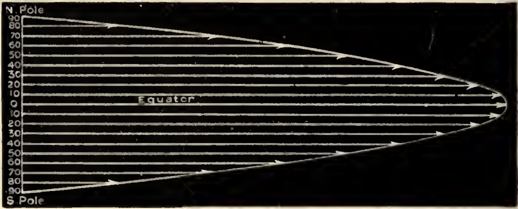


FIG. 261.—Graphic representation of velocities in different latitudes due to the rotation of the earth.

hours, the velocity of its equatorial region must be something like 1,000 miles an hour. But, on going either north or south from the equator, the circle which is described by any point on the rotating sphere will be smaller, as is shown by the diminution in the diameter of the circles of latitude. Yet every point of the surface takes the same time to turn once round; and therefore the velocity, or rate of motion, must become less and less as the circles get smaller and smaller. In fact, at the poles, the velocity is reduced to nothing (Fig. 261). The pole represents simply the end of the imaginary line on which the earth turns, and is itself stationary.

Effects of varying velocities.—Everything on the surface of the earth is necessarily carried round with the rotating globe; and in consequence of the difference of velocity of points in different latitudes, winds and ocean currents undergo a deviation of direction. The atmosphere, as shown in Chapter VI, may be regarded as part and parcel of the earth; it forms, in fact, a gaseous shell, which completely encases the globe and shares in all its movements. The atmosphere, therefore, moves round at the same rate as the surface on which it rests. But this surface rotates, as just explained, at different speeds in different latitudes; and hence the atmosphere, while quiescent over the poles, moves with increasing rapidity in lower latitudes, until it attains 1,000 miles an hour at the equator. Therefore, if a stream of air starts from one of the poles towards the equator, and moves in a direct north-and-south line—that is to say, along a meridian—it will constantly tend to lag behind the surface of the earth. At the starting-point the air is stationary because the pole itself has no motion; and, if we could suppose such a stream of air to flow due south without coming into contact with anything, the successive points of the earth's surface over which it passed would turn under it with constantly-increasing swiftness, until, at the equator, they would whirl by at the rate of 1,000 miles an hour to the east.

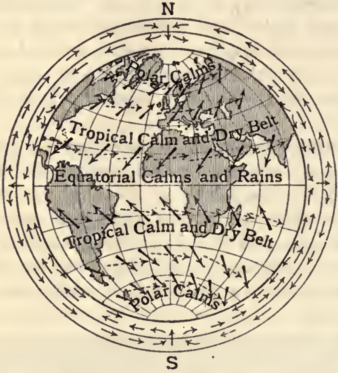

N
Polar Calms
Tropical Calm and Dry Belt
Equatorial Calms and Rains
Tropical Calm and Dry Belt
Polar Calms
S

FIG. 262.—General direction of circulation of the atmosphere due to warm air rising in the tropics and flowing toward the poles, while currents flow along the surface to take its place. The directions of winds are shown by arrows on the globe, upper currents being indicated by broken lines. (After Tarr.)

Deflection of winds moving toward the equator.—As a matter of fact, a stream of heated moist air constantly rises, by its relative lightness, from the neighbourhood of the equator, where the heat is greatest and the evaporation most rapid (Fig. 262). To supply the place of the air which is thus raised, colder and denser air rushes in from the north and the south of the tropical zones. Yet this inflowing air does not take the shape of a due north wind in the one hemisphere and of a due south wind in the other hemisphere. The air comes from places where the velocity of rotation is less, and therefore it lags behind the earth in its rapid rotation from west to east. Hence the wind reaches the equatorial zone from the north-east on the north side, and from the south-east on the south side, of the equator. In this way it comes about that winds, more or less constant in direction, blow across those parts of the Atlantic and Pacific oceans which lie for some distance on the two sides of the equator, the direction being from north-east in the northern tropics and from south-east in the southern tropics. Such steady winds following a nearly constant course are called **trade-winds** (Fig. 263). It may be well to remark here that winds receive their names from the quarters *from* which they blow. Ocean currents, however, are generally named after the point *toward* which they set. Hence a north-east wind blows from the north-east; but a north-east current flows to the north-east.

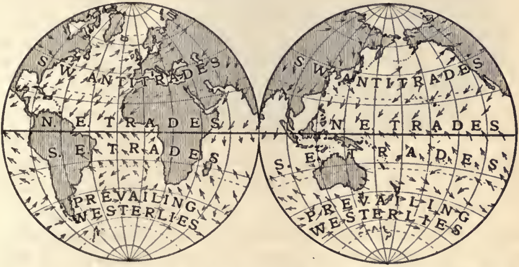


FIG. 263.—General direction of trade-winds (N. E. and S.E.) and anti-trade winds (S.W and N.W.).

It has just been said that the trade-winds blow in a direction more or less constant. This qualification is needed, because the character of the wind is greatly modified by local circumstances, such as the distribution of land and water, and the altitude of neighbouring land. The trade-winds are not equally well marked in the two great oceans; nor are they equally strong at all seasons.

The seasonal differences are due to the fact that the heat equator (see p. 102) has not a constant position, being farther north of the geographical equator in our summer than in winter. The periodical winds known as **monsoons,** experienced in India, China, and adjacent regions, may be regarded as modified trade-winds. During the summer months these seasonal winds blow from the south-west, and the moisture they carry is deposited as rainfall on India and Southern Asia (Fig. 264). As the belt of greatest heat moves south of the equator, following the apparent annual movement of the sun, the winds change their direction, and from October to April the dry north-east monsoon blowing from the Asiatic continent takes the place of the wet south-west monsoon, which prevails from April to October.

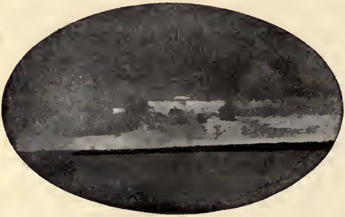


FIG. 264.—Monsoon cloud at Bombay one hour before the "burst" on June 11, 1903. Photographed by Mr. B. Mundy.

Winds moving toward higher latitudes.—It may be inquired, What becomes of the air which rises from the heated equatorial belt? This air, on reaching the higher regions of the atmosphere, flows over the currents which are sweeping across the surface below, and thus produces currents which drift towards the north in the northern, and towards the south in the southern hemisphere. But these upper currents are blowing from regions of high velocity, to regions of lower velocity, of rotation; they therefore move more rapidly than the earth immediately beneath them, and, as it were, outrun the earth in its rotation. Hence they are deflected from a simple north-and-south course, but in an opposite direction to that of the trades; so that, in the northern hemisphere, they blow from the south-west, and, in the southern hemisphere, from the north-west. Such upper currents, moving directly counter to the surface winds, may be recognised by their effects on high clouds.

In the higher regions of the atmosphere they become chilled; and, at about the thirty-fifth parallel of latitude, they are sufficiently dense to descend to the surface. Part of this air then returns as an undercurrent to the equatorial belt, where it becomes heated afresh, and once more rises, thus completing the circulation in this part of the atmosphere; while another part of the descending air continues its course as a south-west wind in the northern hemisphere, and as a north-west wind in the southern hemisphere; but these winds are not so constant as the trades. The prevalent **south-west winds** of the British Isles may have, in part, such an origin. These winds are the chief rain-bearers to these islands; and hence the rotation of the earth is not without its effect upon the water-supply of our country.

Revolution of the earth.—The diurnal rotation of the earth does not explain all the apparent movements of the heavenly bodies. For example, it is observed that the sun does not rise, day after day, in exactly the same place. At the beginning of spring and autumn it rises almost precisely due east; but, in midsummer, it rises to the north of the east point of our horizon, and, in mid-winter, it rises to the south of this point (Fig. 265). The sun seems, in

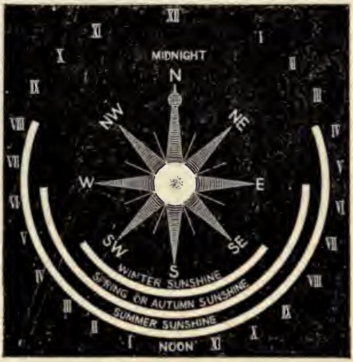


FIG. 265.—Graphic representation of duration of daylight in the latitude of London in different seasons. The ends of the bright strips show the points of the horizon where the sun rises and sets. Adapted from a diagram by Mr. R. Bentley.

fact, to change its place in the heavens every day, but the circuit of changes is completed in the course of a year; so that, next midsummer, it will be again in just the same place as that which it occupied last midsummer. Its apparent movement is, in fact, due to the movement of our earth around the sun, in a direction, like that of its rotation, from west to east. And, just as the time of one rotation of the earth on its axis constitutes a **day**, so the time of one revolution round the sun makes a **year**.

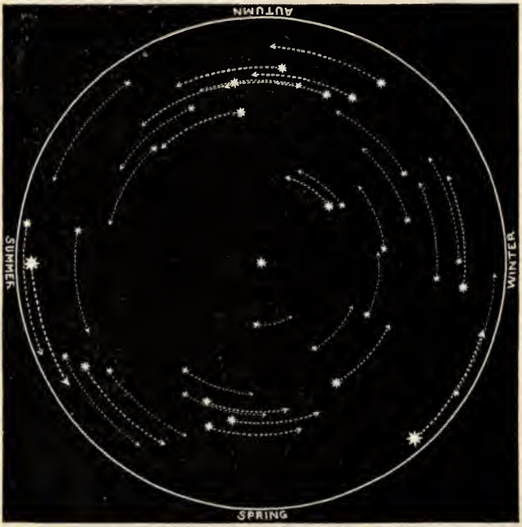


FIG. 266.—Apparent rotation of stars around the north celestial pole. Arrange the diagram so that the name of the season can be read at the bottom, and the stars then occupy the position in which they can be seen about 10 P.M.

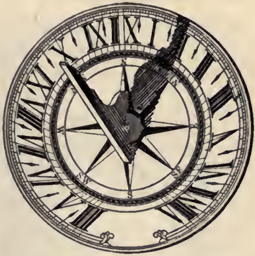


FIG. 267.—Style and dial of a horizontal sun-dial.

Sidereal and solar days.—The exact time taken by the earth to make one complete spin on its axis is determined by observations of the stars. If the stars be watched on a clear night for a short time, it will be observed that many of them appear to move across the heavens, from the east to the west, in the same way as the sun does during the day; and, if any one of these stars were bright enough to cast a shadow, we might make a star-dial for the night, just as sun-dials are made for the day. Suppose that one of the stars which never set in England, such, for example, as the star in the end of the tail of the Great Bear (Fig. 266), could be seen during the whole of its apparent daily course around the north pole of the heavens. The star would be found apparently to describe a complete circle in 23h. 56m. 4s., which period of time (86,164 seconds) is termed a **sidereal day** and represents the period of rotation of the

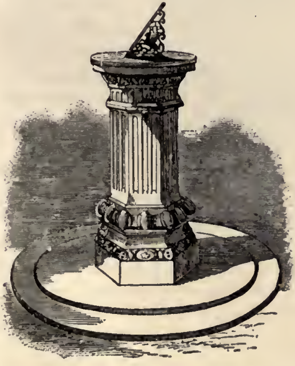


FIG. 268.—Sun-dial in Inner Temple Garden, London.

earth on its axis. If the sun is observed instead of a star, a day of different length is found. In the first place, the interval between the time when the shadow on a sun-dial marks noon on one day, and the time it marks noon on the next day, is always more than 86,164 seconds; and in the second place, the difference is not always the same, but is sometimes more and sometimes less. If the sun-dial were a clock, in fact, we should say that it did not go very well; and the only way of using sun-dial time or **apparent time** for ordinary purposes of life is to strike an average of all the irregularities of the sun-dial during a year. This average is 236 seconds, which, added to 86,164, gives the 86,400 seconds which compose the 24 hours or **mean solar day** of civil time.

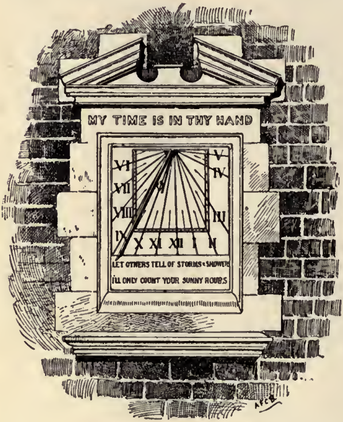

MY TIME IS IN THY HAND
VI
VII
VIII
IX
X
XI
XII
I
II
III
IV
V
LET OTHERS TELL OF STORMS & SHOWE
I'LL ONLY COUNT YOUR SUNNY HOURS

FIG. 269.—Sun-dial on south wall at Sandringham.

The revolution of the earth around the sun occupies 365¼ days; or more precisely 365 days, 6 hours, 9 minutes, 9 seconds of mean solar time. As the calendar year contains 365 days, the extra quarter of a day gives an additional day every fourth year, or **leap year**; and, by this addition, the correction necessary to cause the seasons to fall in the same months of every year is nearly made.

Apparent annual motion of the sun.—It is in consequence of the annual motion of the earth that the sidereal day, or day reckoned by the apparent movements of the stars, is nearly four minutes shorter than the mean solar day. The sidereal day represents the period of the earth's rotation, but the solar day is due, not simply to the rotation, but to this movement combined with that of the earth's progressive movement through space. Suppose that it were possible to see the sun, and at the same time a certain star, on the meridian together at noon to-day; then it would be found to-morrow that the star reached the same meridian nearly four minutes before the sun came there (Fig. 270). But it is clear that, if the earth simply rotated upon its axis, the star and the sun ought to reach the meridian at the same time. The delay in the sun's arrival is due to its

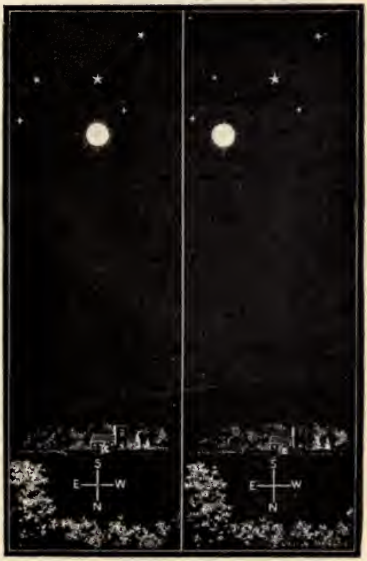


FIG. 270.—Solar and sidereal days. If the sun and a star are due south together on any day, the star is due south four minutes before the sun on the next day.

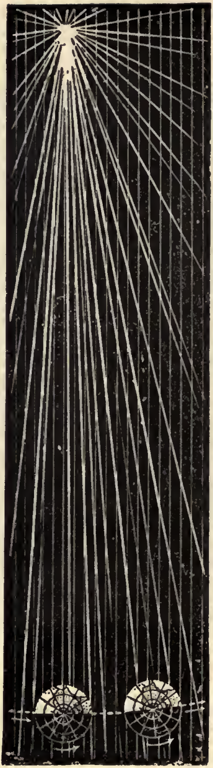


FIG. 271.—To explain the difference of length of solar and sidereal days. The faint parallel lines represent rays from a star: the radiating lines are rays from the sun.

apparent journey in the heavens, which is opposite to that of the diurnal rotation of the stars, so that the sun appears to move backwards among them. The stars are so extremely far off that their apparent position is not sensibly affected by our yearly march round the sun; but the sun is so much nearer, that its apparent position is materially affected, and the sun consequently seems to lag behind every day. As a complete revolution is effected in the course of a year, $\frac{1}{365}$th part of the journey will be accomplished in a day. But a circle is divided into 360 degrees: therefore nearly one degree will be travelled over every day. Now the 360th part of 24 hours is 4 minutes; hence the change of position, due to one day's apparent *annual* motion of the sun, is equal to the change of position due to about four minutes apparent *daily* motion (Fig. 271).

Inclination of the earth's axis.—The position which the earth occupies in relation to the sun, at different periods of its annual journey, will be understood by reference to Fig. 272. This shows the earth at four successive positions corresponding to the four seasons. The track which the sun appears to follow in the heavens, in consequence of our motion round him, is called the **ecliptic.**[1] If it be supposed that a flat surface passes through this path, and through the centres of the earth and sun, that surface will form the **plane of the ecliptic,** and will coincide with the plane of the earth's orbit. The earth's axis is neither in this plane nor perpendicular to it, but is inclined to the plane. It is in fact sloped, as represented in the figure, at at angle of 66° 32′; and the extent of the slope remains the same in every part of the earth's path; in other words, the axis may be said to remain parallel to itself, and to point to

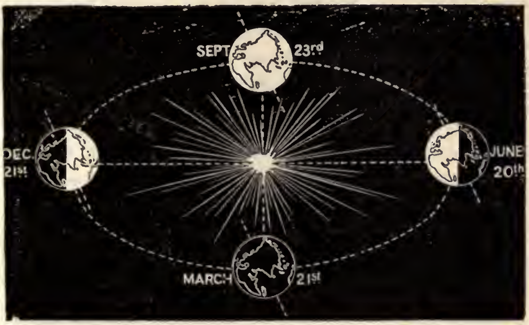


FIG. 272.—Positions of the earth in its orbit at the solstices and equinoxes.

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[1] *Ecliptic*, so called because *eclipses* only happen when the moon is either on or very near to this curved path.

the same spot of the heavens.[1] Great as the diameter of the earth's orbit is, it is insignificant when compared with the enormous distances of the so-called fixed stars. If, therefore, the north pole of the earth points towards the pole-star at one part of the earth's orbit, it continues to point towards it all through its journey, though that journey forms an enormous circuit in the heavens. If one walks in a circle ten yards in diameter, the apparent direction of objects fifty yards off will be obviously altered at every step; but the change of bearing of the spire of a distant church can only be detected by the use of a surveying instrument called a theodolite; and that of a remote mountain-top will appear to remain unchanged, even with such help. If the same circle is taken to represent the orbit of the earth, the nearest "fixed" star would be at a point more than twelve hundred miles distant from it.

Summer and winter.—Reference to Fig. 272 will now show plainly enough how the inclination of the earth's axis affects the amount of light and heat which the globe receives from the sun at different seasons. Suppose that the earth is in the position which she occupies on June 20, represented in the figure. Here it is seen, that the inclination of the axis causes the north pole to be fully exposed to the sun; and the sun-lit half of the earth includes much more of the northern, than of the southern hemisphere. As the earth turns round this sloping axis, the north pole and the surrounding parts will continue in sunshine during the entire rotation. Within a circle measuring 23½° from the north pole, the sun will not set; and, within a similar circle around the south pole, the sun will not rise. Anywhere outside the polar regions, there will be an alternation of day and night during the 24 hours; but the day and night will not be equal, except at the equator. Thus, a place in the northern hemisphere, like London, will have the day much longer than the night; for the figure shows that it will be kept, during rotation, longer in sunshine than in shade. In fact, when the earth is in this position, it is **midsummer** in the northern hemisphere; and, as the figure shows, it is **midwinter** in the southern hemisphere.

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[1] It should be mentioned, however, that the earth's pole undergoes a slow change of position, so that it does not always point to exactly the same spot in the heavens. But this movement is so slow that it would take 25,800 years for the pole to make a complete revolution.

Lengths of days.—As the earth travels round the sun, from June to September, it completes a quarter of its circuit. The days in the northern hemisphere have been getting shorter, and the nights longer; and when the earth has reached the position of autumn in Fig. 272, or on September 23, one-half of the illuminated face of the earth is in the northern hemisphere and the other half is in the southern hemisphere. As the axis always points in one direction, it does not now incline towards the sun as it did when in the June position, and the north and south poles are now at the same distance from the sun. The boundary between the illuminated and the shaded halves runs directly along a meridian, from pole to pole. Every place on the earth's surface will therefore be just as long in sunshine as in shade; and there will be equal day and night throughout the world.

In passing from the position of autumn to that of our winter, the nights in northern latitudes get longer, and the days shorter. When the earth is in the position of winter, which is about December 21, it presents exactly opposite conditions of light and shade to those of June 20. In fact, the north pole is now turned as far as possible from the sun, and the north-polar regions revolve in darkness, while the southern polar regions are enjoying uninterrupted day.

During the remaining half of its revolution, from summer to winter, the earth passes through successive stages, similar to those just described, but in an inverse order. When it has reached the spring position indicated in the figure, which it will do on March 22, there is again twelve hours' sunshine in all parts of the world.

Equinoxes and solstices.—It will now be understood that, twice in the course of the year, when the earth is at opposite points in its orbit, the days and nights are everywhere equal. These periods are known as the **equinoxes.**[1]

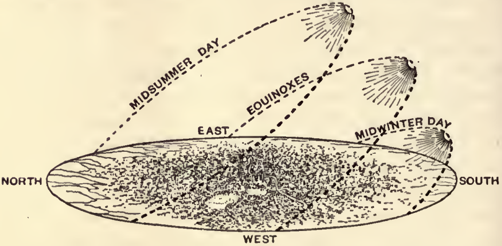

FIG. 273.—Apparent paths of the sun as seen from London at the solstices and equinoxes.

One occurs on March 21, and is therefore known as the **spring** or **vernal equinox**, and the other on September 23, and is consequently called the **autumnal equinox**. Again, there are two other times, also, when the earth is at opposite points of its path, when the inequality between the days and nights is greatest. These occur on June 20 and December 21, and are known as the **summer** and **winter solstices**[2] respectively. On any day of the year, the shadow of a perpendicular object is shortest when the sun reaches the highest point of its apparent diurnal path, that is, at **apparent noon.** If the length of the noonday shadow of such an object is observed, it will be found to vary from day to day throughout the year. In the summer, when the sun is high in our sky, the shadow at apparent noon is comparatively short, and from midsummer to midwinter it gradually lengthens, while from midwinter to midsummer it gets shorter and shorter day by day. Observation of these varying shadows will show that the sun's altitude or angular height above the horizon is least at the winter solstice and greatest at the summer solstice. But, even at midsummer in England, the noonday altitude never exceeds about two-thirds of the distance from the horizon towards the zenith (Fig. 273).

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[1] *Equinox*, from Lat., *æquus*, equal; *nox*, night.

[2] *Solstice*, from Lat., *sol*, sun; *sisto*, I stand: because the sun appears to stand at the same noonday altitude for several days when at these points of its apparent path.

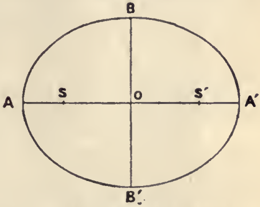

FIG. 274.—An ellipse. A A′, major axis; B B′, minor axis; S, S′, foci; O, centre.

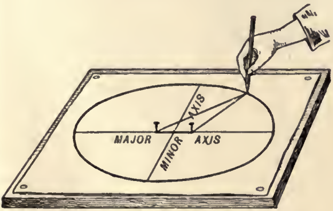

FIG. 275.—Construction of an ellipse. Each of the pins is situated at a focus of the ellipse.

Shape of the earth's orbit.—In discussing the earth's revolution round the sun, it should be mentioned that the orbit is not strictly a circle, but is a curve of that kind which was described in the last chapter as an ellipse. In an ellipse (Fig. 274) the longest diameter, A A′, is called the **major axis**, and the shortest diameter, B B′, the **minor axis**. On the major axis, there are two points which have this property:—If two straight lines be drawn from these two foci to meet at any point on the curve, the total or combined length of these lines is always the same (Fig. 275). These two points are known as the **foci** of the ellipse. In the great elliptical path of the earth, the sun occupies one of these foci, as at S in Fig. 274. It is plain, therefore, that, when the earth is at A, it must be nearer to the sun than when at A′. The nearest distance is called the **perihelion**,[1] and the greatest distance the **aphelion**.[2]

Seasons.—It would, at first sight, seem a very fair assumption that when the earth is at perihelion it should be hottest, because it is then at its nearest point to the sun. As a matter of fact, however, the earth is at perihelion on January, which is almost the coldest part of the year in the northern hemisphere; and it is at aphelion about the beginning of July (Fig. 276). There are, indeed, several influences which tend to neutralise the effects of the sun's proximity. Thus, when the earth is at perihelion, the days with us are short, for the sun is not long above the horizon. Nor does it rise high in the sky, at this season; and, hence,

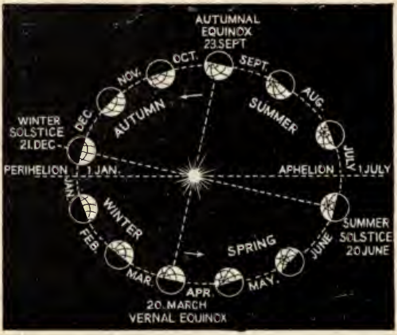

FIG. 276.—The earth in its orbit round the sun.

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[1] *Perihelion*, from περὶ, *peri*, near; ἥλιος, *helios*, the sun.

[2] *Aphelion*, from ἀπο, *apo*, from; and ἥλιος.

the rays fall very obliquely upon the earth; so that they have less heating effect than if they fell more directly upon the surface (Fig. 277). Again, it must be remembered that the earth moves more rapidly as it approaches the sun. These influences more than neutralise any augmentation of heat which may be due to increased nearness to the source of heat; hence, the apparent paradox, that the earth is nearer to the sun during our winter than during our summer, becomes easily intelligible.

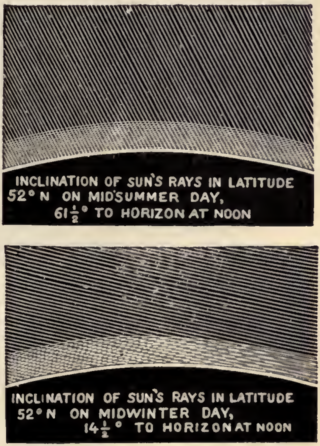

FIG. 277.—To show how the sun's rays strike the atmosphere in summer and winter.

It is evident that the temperature of any locality depends chiefly on the duration of its supply of sunshine, and on the direction in which the sun's rays are received. If days and nights were of equal length throughout the year, and had the same altitude every day at noon, there would be no seasons. But when the sun is above the horizon for more than twelve hours, the gain of heat by day exceeds the loss by night, and when the days are less than twelve hours long, the loss is greater than the gain. It is on account of the storage of heat by land and water that the hottest time of the year in England is not at midsummer, when the sun rises highest in the sky, but two months or so later.

Zones and tropics.—At the equator the sun is directly overhead, or in the zenith, at noon in the spring and autumn, and is never more than 23½° from the zenith, at either solstice; while the days and nights are of practically equal length all the year round. Within a circle of 23½° latitude, on each side of the equator, there is a belt called the **torrid** or **tropical zone.** At every place within these zones, the sun is in the zenith twice a year, and is never more than 47° from the zenith. Hence the intense heat of tropical regions. The boundaries of these zones are called **tropics**; and the countries just outside these circles form **sub-tropical** regions.

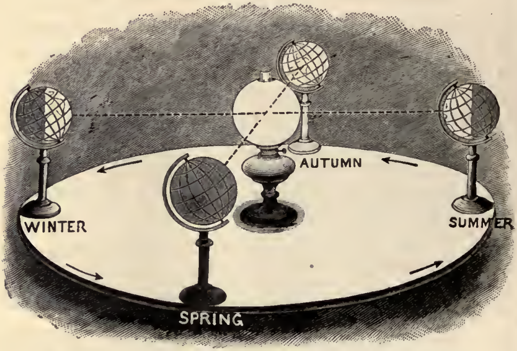

FIG. 278.—Experimental illustration of the cause of seasonal changes.

Around each pole, a circle of 23½° radius may be drawn, which will include the **polar** regions or **frigid zone.** The northern circle is called the **Arctic,** and the southern is called the **Antarctic** circle. At the poles themselves, the sun is above the horizon for six months continuously, and below it for an equal period. But, though the polar day is so long, the extreme obliquity of the rays prevents the continued sunshine from having so great a heating power as it would have further south. In fact, at the poles the sun never rises more than 23½° above the horizon.

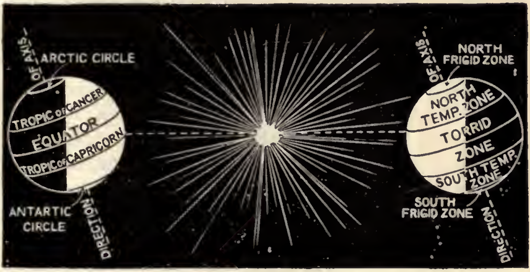

FIG. 279.—The earth at the two solstices, showing how the inclination of the axis determines the positions of the tropics of Cancer and Capricorn, and the width of the climatic zones.

Between the polar and the tropical zones there is, in each hemisphere, a broad belt of the earth's surface, which is known as the **temperate** zone. The distribution of these zones on the surface of the globe is shown in Fig. 279.

Climate.—The zones on the earth's surface are distinguished, as has just been explained, by their differences of climate. The principal factor in the formation of climate is, of course, solar heat; the climate of any place depending primarily on the lengths of the days and nights, and on the relative duration of the seasons. But climate is also greatly affected by the nature of the surface, whether it be land or water. Water parts with its heat much more slowly than the land does, and it thus retains a store which serves to equalise the temperature. On land again, the climate depends, to a very great extent, on the altitude. In fact, on ascending a high mountain from a plain in a hot country, the traveller meets with changes in the character of the animal and vegetable life, which are similar to those changes which may be observed in passing from low to high latitudes. Even within the tropical zone, the highest points of the existing high lands are covered with perpetual snow. Climate is also modified by winds, which transport heat and moisture from one place to another, and by marine currents.

Changes of climate.—Climate determines, to a very large extent, the character of the animal and vegetable population of a country, or its fauna and its flora. From a study of the past history of the British Isles, as revealed by the organic remains found in the various rock formations, it is evident that this area has at different times undergone great vicissitudes of climate; at one time supporting a tropical or sub-tropical vegetation, and at another time offering a congenial feeding-ground to herds of northern mammals, such as the musk-sheep. These differences of climate may be partially accounted for by alterations in the relative distribution of the masses of land and water; but some of the climatic changes appear to have been so extreme, that the geologist has been led to seek their explanation in astronomical causes.

It has been suggested, for instance, that at different periods in the past the sun has emitted varying quantities of heat, but no substantial evidence of fluctuations sufficient to account for the vicissitudes of geological climates has been brought forward. The late Dr. Croll developed in detail a theory that secular changes in the eccentricity of the earth's orbit were sufficient to account for variations of climate, and Sir R. S. Ball has supported the argument; but a critical examination of the effects which would be produced by such changes has shown that this astronomical explanation of Ice Ages and Genial Ages in the past is inadequate. It has been shown that the change of climate from this cause would be somewhat less than the changes due to variation in the distribution of land and water; and if this conclusion is accepted, the eccentricity theory must be abandoned. Many other causes of changes of geological climates have been suggested, but none has met with complete acceptance. Slight variations in the constitution of the earth's atmosphere in the past would have a very decided influence upon climate, and though they do not provide a complete solution of the problem, they probably constitute a very important factor in it.

CHAPTER XX

THE SUN AND GRAVITATION

REFERENCE has frequently been made, in the course of the foregoing chapters, to the effects of solar heat upon the earth. Such references, however, have been incidental rather than direct; and little or nothing has been said, of set purpose, about the sun itself. It is proposed, therefore, to give in this concluding chapter a simple sketch of what we know about the nature of the sun; and to show that the influence of this body may be regarded as the prime mover in the production of most of the phenomena which have been described.

The visible disc.—When the sun is shining in its full splendour, it is much too dazzling an object to be looked at with the unprotected eye. Viewed, however, through a misty atmosphere, or through a dark-coloured glass, it presents the appearance of a luminous disc, which is usually perfectly circular in shape and homogeneous over its entire surface. When the sun is near the horizon, the shape of its disc is sometimes distorted by atmospheric refraction, and occasionally dark spots can be seen upon it with unaided sight, but in general only an immaculate circular surface meets the eye. The size of this bright disc does not, however, remain precisely the same throughout the year. It was explained in the last chapter (p. 382) that, in consequence of the shape of the earth's orbit, we are not always separated from the sun by the same distance; being, in fact, much nearer in December than in July. This difference of distance causes a corresponding difference of apparent magnitude in the solar disc (Fig. 280). The apparent size of an object, as every one knows, varies according to the distance at which it is viewed, so that a halfpenny held at arm's length may actually seem larger than the entire sun.

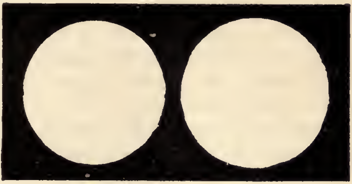
July 1. January 1.

FIG. 280.—Variation in apparent size of the sun due to the revolution of the earth in an elliptical orbit, having the sun at one focus.

Angular diameter.—Suppose that you are looking at a man, A B, some distance from you (Fig. 281); his apparent height will be measured by the inclination of the two lines, A O, B O, which are drawn from the top of his head and the ground at his

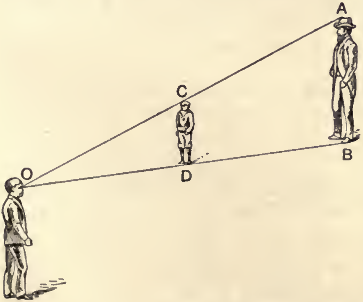

FIG. 281.—The boy, C D, is half the height of the man, A B, but he appears to be the same height, because he is at half the distance of A B from O.

feet to the centre of your eye. A taller man will give a larger angle, and a shorter one a smaller angle. The apparent height of the man will therefore depend upon the angle which the man forms, or subtends, at the eye. If a boy, C D, comes in the line of sight, he may be so placed as to subtend precisely the same angle. Hence, a small body near to the eye may appear just as big as a large body which is farther away.

Size of the sun.—It is easy to understand from such a diagram as Fig. 282 the *principle* of the method of determining the actual size of the sun in miles from measurements of the angular dimensions. Let a circular disc, say one inch in diameter, be cut out of cardboard; or take the halfpenny mentioned above, for this has exactly the diameter of one inch. Let the disc, or the coin, be held at such a distance from the eye that it just covers the solar disc; the object being kept square to the line of sight. It will be found that the required

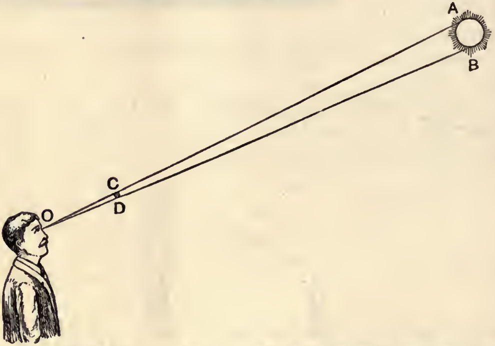

FIG. 282.—The diameter of the sun, A B, is so many times greater than that of the halfpenny, C D, as the distance of the sun (93,000,000 miles) is greater than the distance of the halfpenny (9 feet) from O.

distance is about nine feet. Now, on reference to Fig. 281, it will be seen that the man A B has exactly twice the height of the boy C D, and that he is also at exactly twice the distance; in these circumstances the two bodies appear to the eye at O to have precisely the same height. To speak generally, the actual heights of two objects which have the same apparent height are directly proportional to their distances. Hence, the distance of the halfpenny bears to the distance of the sun just the same ratio that the actual diameter of the halfpenny bears to the actual diameter of the sun. The actual diameter of the sun is therefore found by a simple rule-of-three sum; provided, of course, that the sun's distance be known. Astronomers have measured this distance, by methods too complicated to be described here, and have found the mean value to be nearly ninety-three million miles. Hence it follows that the diameter of the sun—that is to say, the distance measured from side to side through the centre of the sun—is about 866,500 miles. The sun's diameter is therefore more than 109 times as great as the earth's diameter.

This comparison refers only to **diameters**. If sections of the sun and of the earth were made exactly through the centre of each, the **area** of the sun's section would be 109 times 109 times as great as the earth's section. And if the **volumes**, or bulks, of the two bodies were compared, it would be found that the sun's bulk is 109 × 109 × 109 times greater than the earth's bulk. In other words, it would require more than a million and a quarter of bodies having the same bulk as the earth, to be rolled together, in order to form a globe equal in size to the sun.

No adequate notion of the dimensions and of the distance of the sun is gained by casting the eye over the figures which represent these magnitudes. But some conception of its enormous size may be formed by reference to Fig. 283, which shows a section of the sun, taken through its centre, compared with a similar section of the earth, and some of the other planets which revolve around the sun. It was shown in Chap. XVIII that the earth is a ball of vast dimensions; but it is seen, by Fig. 283, that this huge ball sinks into utter insignificance when compared with the mighty sphere around which it revolves.

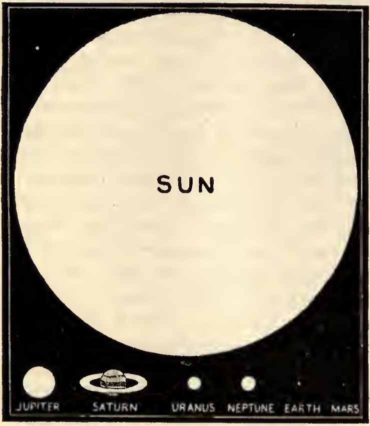

FIG. 283.—Comparative sizes of the sun and some of the planets.

Distance of the sun.—As to the distance of 93,000,000 miles which separates the sun from the earth, that may be represented in a variety of ways; but by none perhaps more strikingly than by the statement that a bullet from a Maxim gun, though it leaves the muzzle with a velocity of 2,000 feet per second, would take seven years to reach the sun. Light, which travels with a velocity of 186,000 miles a second, does the journey in eight minutes.

Sun-spots.—Soon after the discovery of the telescope, it was directed to the examination of the solar disc. It was thus found, in the beginning of the seventeenth century, that the sun's face, instead of being uniformly bright, is often spotted with patches which appear dark, inasmuch as they are less luminous than the intensely bright surface which surrounds them. Very little observation is needed to show that these spots are not constant, either in shape or in position; sometimes indeed, though but rarely, they are altogether absent, and the face of the sun then seems perfectly pure. If the spots are watched day after day, they may be seen to march slowly across the disc, all moving in the same direction from the eastern edge or **limb**, that is, the edge facing our eastern horizon, toward the western limb, and completing the march in about fourteen days. A fortnight afterwards, some of the very same spots which were lost may possibly reappear on the eastern edge, though altered in shape. This regular movement of the spots teaches us that the sun rotates on its axis, and thus resembles the earth. The direction of rotation is the same as that of the earth, namely, from west to east; for though the spots are carried from east to west with reference to an observer on the earth, the edge or limb facing our east is really the western edge of the sun, and that facing the west is the eastern edge. One rotation of the sun is accomplished in about twenty-six of our days; but on account of

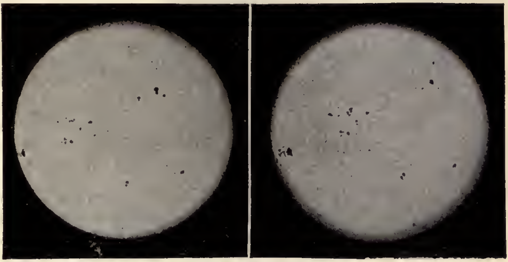

FIG. 284.—The sun and sun-spots. From photographs taken on two successive days.

the earth's revolution around the sun the apparent period of rotation is about twenty-eight days.

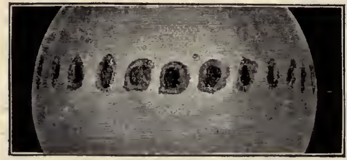

FIG. 285.—Variation of apparent form of a sun-spot, due to foreshortening.

From the different forms which the same spot appears to assume, in passing across the disc, it may be inferred that the shape of the sun is spherical; an inference which has been abundantly corroborated by other observations. A given spot, when near to the margin of the disc, is foreshortened, and presents quite a different appearance from that which it shows when in full view near the centre of the disc. This effect is clearly shown in Fig. 285, which represents views of the same sun-spot in different positions on the disc.

Spots do not appear on all parts of the sun's surface, none being seen near the poles, and rarely any at the sun's equator. The zones to which they are usually confined extend from about 5° to 35° of solar latitude, both north and south, and may be compared to the belts in which trade winds blow on the earth. In addition to the general trend due to the sun's rotation, spots have movements of their own; moreover, those near the equator are carried round the axis in a shorter period than spots in higher latitudes. Every part of a solid globe must evidently be carried round the axis in the same time, as in the case of the earth; hence the independent movements of different layers of the sun show clearly that it is not a rigid body.

Nature and changes of sun-spots.—As so much of our knowledge of the sun has been derived from a study of its spots, it is worth while to inquire a little more closely into their nature. Reference to Fig. 286 will show that a spot is not equally dark throughout; the fringed margin, represented by a half-shade in the figure, is called the **penumbra**,[1] while the darker shade represents the **umbra**; and within the umbra itself there may sometimes be detected a yet darker part, which is called the **nucleus**. There is reason to believe that most spots are nothing but gigantic depressions in the general level of the sun in which they occur; and these becoming filled wth cooler vapours and gases are relatively darker than the neighbouring surface. The intensely luminous part of the sun, which is the seat of these spots, is called the **photosphere**[2] (Fig. 287). It appears to consist of incandescent cloudlike matter, which is subject to violent disturbances, either by eruptions from below or by

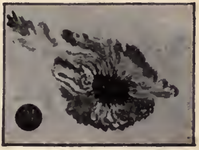

FIG. 286.—Structure of a normal sun-spot. The black spot represents the earth, drawn on the same scale.

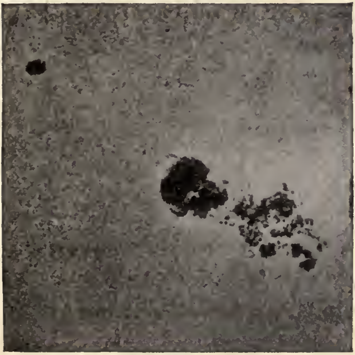

FIG. 287.—Sun-spots and mottled structure of the sun's surface. From a photograph by Dr. Janssen.

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[1] *Penumbra*, from *pæne*, almost; *umbra*, a shadow.

[2] *Photosphere*, from φῶς, *phos*, light; the light-giving sphere.

cool matter descending from higher regions, sun-spots being produced as the result of the action. The rapid changes in the shape of certain sun-spots indicate the violence of this action. Some of the spots are so large as to occupy millions of square miles on the sun's surface.

Periodicity of sun-spots.—Spots may be regarded as storms on the sun, analogous to cyclones on the earth, and of the same transient nature. Observations extending over many years have revealed a peculiar periodicity of solar activity, as indicated by the number and extent of spots. When the total amount of spotted surface from year to year is tabulated, it is found to increase and decrease regularly in a period of a little more than eleven years. For instance, in 1889 the spottedness of the sun was at a minimum stage, days and weeks passing without a single spot being visible. From that year there was a gradual increase in the number and size of spots, and in 1893 the summit or maximum of solar disturbance was reached; after which the solar activity manifested by spots began to decline, until in 1900 the stage of comparative calm was again reached. Delicately suspended magnetic needles on the earth are found to throb

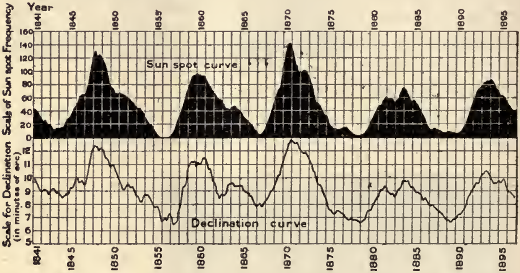

FIG. 288.—Sympathetic change between the amount of spotted surface of the sun year by year and the variation of the earth's magnetism.

in unison with this solar cycle; when the sun is most spotted they are most disturbed, and when solar activity is least they are most restful. Auroras, which are due to electrical disturbances in the upper air, are also found to rise and fall in frequency in correspondence with the sun-spot period. It is possible that the earth's meteorology varies in a similar cycle, but it is modified by so many adventitious circumstances, that no simple relationship such as that existing between magnetic and auroral disturbances and sun-spots can be made out. Sir Norman Lockyer and Dr. W. J. S. Lockyer have found, however, that after three sun-spot periods, or about thirty-three years, certain solar phenomena occur in much the same order and character as before; and as it has been shown that wet and dry seasons follow a cycle of the same length—the average interval between two wet or two dry periods being about thirty-three years—it seems probable that some definite connection between solar and terrestrial weather may yet be established.[1]

Constitution of the sun.—Viewed through a powerful telescope, the whole visible surface of the sun seems to be coarsely mottled (Fig. 289). This mottling is probably due to interspaces or irregularities in the surface of luminous clouds. Lower levels are indicated by the darkened spots, and in these parts light is lost by absorption through the overlying atmosphere; where, on the contrary, the light is unusually bright, there the sun-clouds are probably unusually high: such brilliant patches and streaks are best seen near the dull margin of the solar disc, and are termed **faculæ,**[2] but they occur over a large part of the sun's surface,

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[1] An instructive summary of studies of sympathetic relationships between the sun and the earth is given by Sir Norman Lockyer in a paper entitled "Simultaneous Solar and Terrestrial Changes," presented to the International Meteorological Committee at Southport in 1903 and reprinted in *Nature* of February 11, 1904 (vol. 69, p. 351).

[2] *Facula*, a little torch, diminutive of Lat. *fax*.

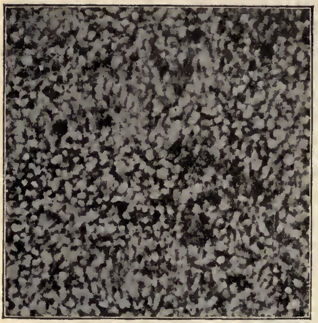


FIG. 289.—Minute structure of the sun's visible surface. From a photograph taken by Dr. Janssen at the Meudon Observatory. Only a small part of the solar surface is here shown.

and are particularly noticeable around sun-spots and in the sun-spot zones.

Above the luminous photosphere is another envelope, which is known as the **chromosphere.** During a total solar eclipse, when the sun is obscured by the moon's shadow, the dark disc is seen to be surrounded by a "glory," or fringe of radiant light, which is called the **corona** (Fig. 290). Within the corona, around the margin of the disc, variously coloured **prominences** may be detected; these fantastically-shaped tongues of red flame may be seen to dart forth from the general level of the chromosphere in which they have their origin, sometimes to the extent of 100,000 miles or even to greater distances. In ordinary circumstances, these effects are not visible, in

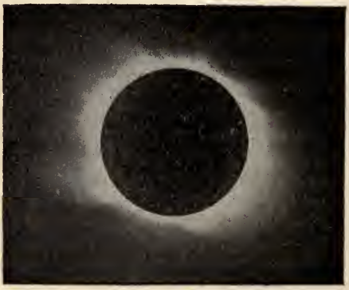


FIG. 290.—The solar corona. Photograph taken by Prof. E. E. Barnard during the total eclipse of the sun of May 28, 1900.

consequence of the overpowering light of the photosphere. But a method was devised by Sir Norman Lockyer and Dr. Janssen in 1868, whereby these prominences may be examined without waiting for an eclipse. Such examination has shown that the red flames consist, for the most part, of the gases hydrogen and helium, which are also the chief constituents of the chromosphere. The radiance of the corona is made up of light from incandescent solid or liquid particles, sunlight reflected from them, and luminous gases in a very attenuated condition, one of which is characteristic of coronal radiations. This gas has received the name **coronium,** but it has not yet been discovered in terrestrial matter.

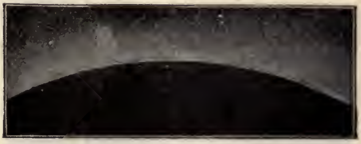


FIG. 291.—Solar prominences photographed during the total eclipse of the sun of May 28, 1900, by Dr. S. P. Langley.

Analysis of sunlight.—It seems almost incredible that a person situated on the earth should be able to learn anything about the chemical constitution of the sun, which we know to be 93 millions of miles away. To attempt to subject the sun to any of the ordinary chemical processes of the laboratory is, of course, quite out of the question; but, during the latter half of the nineteenth century, a new method of analysis was developed whereby a great deal may often be learnt about the chemical composition and the physical constitution of an unknown body, by proper examination of the light which is emitted when the body has been heated until it becomes luminous.

Without entering into a close description of this method, which has been applied with signal success to the examination of the sun and stars, it is sufficient to remark that, when a beam of sunshine is allowed to pass through a small aperture in the wall of a dark chamber, and then to traverse a three-sided glass prism, like the drop of a lustre, it does not fall as a spot of white light, but is turned aside from its course, and spreads out into a broad band, which presents all the colours of the rainbow. This coloured band is called a **spectrum.** The course of such a beam of white light is exhibited in Fig. 292, which shows a slit through which the light is admitted, and the prism upon which the beam falls. The beam is not only deflected from its original path, but also widens into a many-tinted band with red at one end and violet at the other extremity.

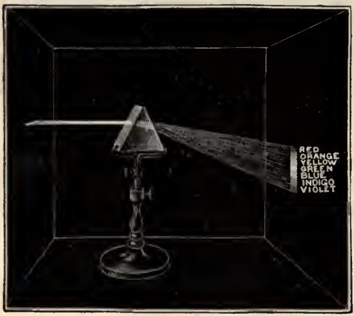


FIG. 292.—When a beam of sunlight traverses a prism it is broken up into a band of colour termed a spectrum.

The solar spectrum.—On closely examining the spectrum of the sun, which has thus been formed by means of a narrow slit and prism, it is found to be crossed by a multitude of fine dark lines, which are indeed so many spaces in the bright band. These lines are called after their discoverer "Fraunhofer" lines. A spectrum obtained from an ordinary gas-flame, or from an incandescent light, differs from the solar spectrum by being destitute of these dark lines; the light of the flame being unbroken from end to end. But, if certain gases or vapours, such as hydrogen or sodium-vapour, be burnt in the path of the artificial light, lines are immediately produced in the spectrum. If the temperature of the substance which produces the lines be lower than that of the substance which gives the continuous spectrum, the lines will appear dark; if the temperature be higher, the lines appear bright. Lines produced in this way have a definite position in the spectrum, so that the same chemical element, under the same conditions, always gives the same set of lines. It is plain, therefore, that, by observing the position of the lines in the solar spectrum, and comparing them with the lines which are produced by the combustion of various terrestrial elements, the presence or absence of such elements in the sun may be inferred. For the examination of the spectrum, special instruments, called **spectroscopes**, are employed; and the method of research itself, which was suggested and worked out by Profs. Bunsen and Kirchhoff in 1859, is known as **spectrum analysis** (Figs. 293, 294).

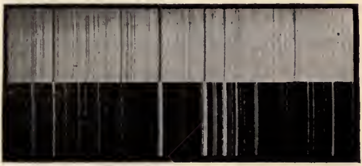


FIG. 293.—Comparison spectra of sun and iron. The upper band shows a small part of the solar spectrum, and the lower shows bright lines in the iron spectrum coincident with dark Fraunhofer lines.

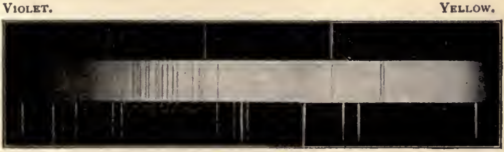


FIG. 294.—The middle band is a part of the solar spectrum, showing dark Fraunhofer lines. The bright lines above the solar spectrum are lines due to hydrogen, and those below belong to the spectrum of helium. Photographed by Mr. C. P Butler.

By means of spectrum analysis, it has been found that the sun contains a large number of elements, including hydrogen, helium, iron, calcium, nickel, sodium, manganese, carbon, magnesium, chromium, silicon, strontium, barium, aluminium, zinc, copper, silver, tin, lead, and potassium. Among the elements which have not been detected in the sun, though they occur on the earth, are gold, mercury, nitrogen, antimony, arsenic, sulphur, and phosphorus.

The sun's light and heat.—From the surface of the sun, enormous quantities of light and heat are continually being radiated, or thrown out into space, in all directions. The earth, however, on account of its small size and its great distance, can receive but an extremely small proportion of the total amount which is thus shed. In fact, it is calculated that our globe intercepts less than the two-thousand-millionth part of the total quantity of the sun's light and heat. All terrestrial phenomena, which depend upon solar light and heat, are therefore effected by means of this extremely minute fraction of the sun's stores of energy.

Gravitational attraction.—The sun is not only the principal source of heat and light to our earth, but it is the centre of attraction by which the revolving globe is maintained in its regular orbit. If a piece of iron be held in front of a powerful magnet, it will rush to the magnet, although there is no visible bond between them. If the same piece of iron be left unsupported in the air, it does not remain suspended, but at once falls to the ground: in other words, it moves towards the earth, just as it moved towards the magnet; though in neither case is there any visible cause of motion. The invisible cause of the motion of the iron towards the magnet is called **magnetism**; the cause of the motion of the iron towards the earth is called **gravitation.**[1]

---

[1] *Gravitation*, from Lat. *gravitas*, weight.

The tendency of bodies to fall towards the earth is called their **weight**; and the nearer bodies on the outside of the earth are to the earth's centre, the greater is their weight. In consequence of the earth's spheroidal shape, a body at the equator is more distant from the earth's centre than when at either of the poles. Hence, a given mass of matter which causes the index of a spring balance to mark one pound in London will cause it to mark rather more than a pound in the polar regions, and rather less than a pound in the equatorial zone. If the same object could be carried into space, to a position far removed from the earth or any other massive body, the spring balance would indicate that it had no weight, though the quantity of matter which it contained would remain unaltered.

Gravitation and revolution.—Gravitation is by no means confined to the earth, but is exerted, in greater or less degree, by every mass of matter in the universe. Of two bodies containing different quantities of matter, each tends to move towards the other, but the amount of motion of each will be less in proportion as its mass is greater. This fact is generally expressed by saying that the two bodies attract one another, and that the greater the mass of either body, the greater is the intensity of its attractive force, provided that the distance separating the two bodies remains unaltered. Now the sun is a gigantic mass of matter, and it attracts all those bodies, including the earth, which circulate around it. At present astronomers are acquainted with about 500 bodies called **planets**, which revolve in regular orbits round the sun. By far the greater number of these bodies are comparatively small and unimportant; but eight of them are large planets, of which the earth is one, though by no means the largest. All these planets are retained in their orbits by their gravitation towards the sun, which forms the great centre of the solar system.

Let a ball be tied to a piece of string and whirled rapidly round; and while revolving in this way let the string be suddenly broken. The ball does not continue to move in a circle, but darts off in a straight course, until brought to the ground by terrestrial gravity. In like manner the earth would rush into space in a straight path if the bond of gravitation, which plays the part of the string, were broken between the sun and the earth. The revolution of the earth in a nearly circular orbit is therefore maintained by means of gravitation.

Tidal action.—Everything upon the earth's surface is subject to terrestrial gravity. Every particle of water tends to fall towards the centre of the earth, and thus the waters of the ocean are bound down so as to form an envelope around the globe. But while the water is thus held to the earth, it is also attracted by all the other components of the universe; and, as the particles of water are free to move, the position of any given particle, and hence the form of the surface of the whole ocean, must be determined, other things being alike, by the balance of all these attractions. Most of the bodies which lie outside the earth are so distant that their influence is inappreciable; but it is otherwise with the sun and the moon. Each of these pulls away from the solid earth the water that lies on the face of the globe which is turned towards it; while, at the same time, it pulls the solid earth away from the water which lies on the opposite face of the globe (Fig. 295).

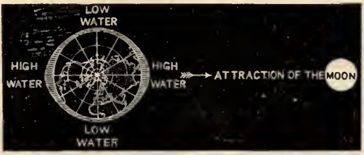


FIG. 295.—Tidal action of the moon.

In any parallel of latitude which traverses nothing but sea, the contour of the latter, if left to the attraction of the earth alone, will be sensibly a circle. Now suppose the sun or the moon to come to any meridian of that parallel, then the attraction of these bodies will convert the contour of the ocean into an ellipse, of which the long diameter will pass through the meridian in question, and that 180° from it; while the short diameter will traverse meridians at 90° from these two.

If, before the intervention of the sun or moon, the water were everywhere of the same depth, it would now be deepest at the two meridians, 0° and 180°, and shallowest at 90° and 270°. In other words, it would be **high water** at the former, and **low water** at the latter meridians.

Solar and lunar tides.—Supposing the sun or the moon to be stationary, it is obvious that, in the course of the diurnal rotation of the earth, every point of the ocean under the parallel of latitude in question will have been twice raised to the height of high water, and twice lowered to the depth of low water; which comes to the same thing as if a wave, with a crest the height of high water and a trough the depth of low water, had passed twice round the parallel in the same space of time.

Thus the rotation of the earth, combined with the attraction of the ocean by the sun and moon, gives rise to solar and lunar **tidal waves.** If the free motion of the waters of the ocean were not interfered with by the ocean floor and the form of the coast line, and if there were no moon, high water would always take place a little after noon and midnight; and low water would be a little after six o'clock in the morning and evening. Moreover, the rise and fall of these solar tides would be much less than our actual tides, for the tide-producing action depends upon the *difference* of the attractive pull at the earth's surface and at the centre. In the case of the moon this difference is greater than that of the sun, so the moon's tidal action is greater than the sun's, though the actual gravitational influence of the sun on the earth greatly exceeds that of the moon. The result is that the tide-raising value of the sun is only about one-half that of the moon.

Spring and neap tides.—The lunar tides, therefore, are much more important than those caused by the sun. If the moon always came to the meridian at the same time as the sun (as is the case at new moon), it is obvious that the lunar tide would strengthen the solar tide, and solar and lunar high waters and low waters would correspond.

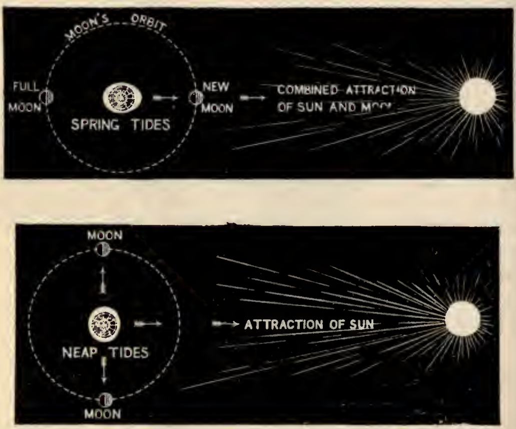


FIG. 296.—Relative positions of the sun, moon, and earth at spring and neap tides. The observer is supposed to be looking down upon the bodies from a point in space.

Again, if the moon were always 180° from the sun (as is the case at full moon), the attractions of both would still conspire, though not so completely, to the same end, and the times of high and low water of both would still coincide.

On the other hand, if the moon always came to the meridian six hours sooner or later than the sun, it is obvious that the two tidal waves would tend to neutralise one another. It would be sun low water when it was moon high water, and *vice versâ*. In the former cases the high or low water would be the sum (or nearly so) of the solar and the lunar high or low waters, while in the latter it would be their difference (Fig. 296).

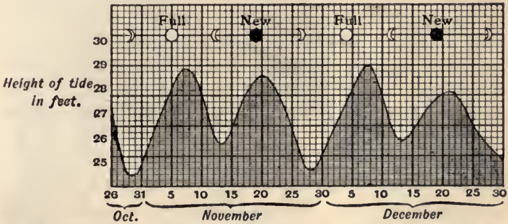


FIG. 297.—Spring and neap tides. The undulating curve shows the depth of water at London and Victoria Docks for each day from October 26 to December 30, 1903. Notice that the spring tides occur shortly after new and full moon, and the neap tides near first and last quarters.

As a matter of fact the moon, revolving round the earth in a lunar month, comes to the meridian about fifty minutes later every day, and constantly changes its position in relation to the sun. Hence, in the course of every lunar month there are two periods (near new and full moon) when the times of solar and lunar high water coincide, and the vertical movement of the water is greatest; and two periods (near the first and third quarters) when solar high water coincides with lunar low water, and the converse, and when, therefore, the vertical movement of the water is least (Figs. 296, 297). The former are called **spring tides**, and the latter **neap tides**.

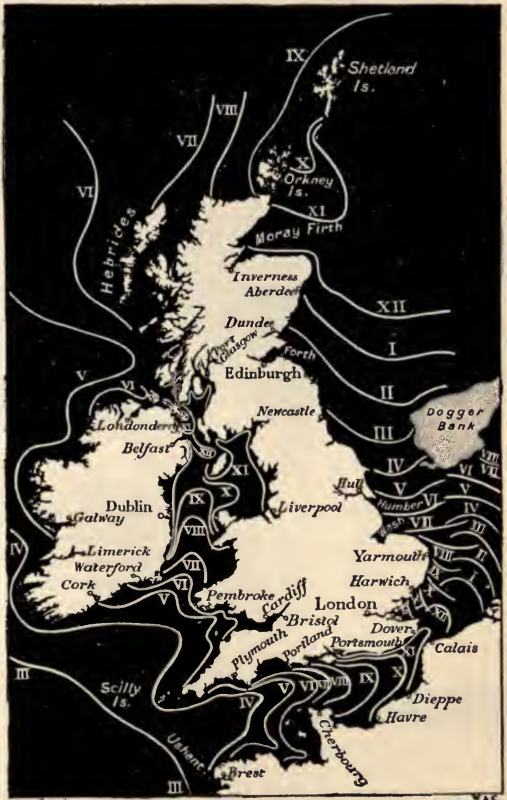
Times of tides.—This simple explanation of the origin of tides is sufficient for our present purpose, but a more elaborate theory is required to account for observed facts as to tides at different times and places. Spring tides rarely occur exactly at the times of new and full moon, and only at a few places is it high water exactly when the moon is over the meridian or on the opposite side of the earth.

On the day of the new moon the sun and moon cross the meridian together (or nearly so) at mid-day. There is then high water at Ipswich, but at London high water does not occur until nearly two o'clock. If the time of high water on the day of new moon is noted at any place touched by tide, it will be found to be the same hour at that place for every new-moon day. At full moon also a clock at a tidal port always shows the same hour when it is high water at that place, and this time is termed the **establishment of the port.**

Not only at new and full moon but on all days in a lunar month the tides follow the moon's course at an interval of time which varies at different places, but is approximately constant at any one place. This interval is the same as the establishment of a port, and when it is known, the time of high tide can evidently be determined from tables showing the times when the moon crosses the meridian of the place.

Progress and range of tides.—As each port has a constant tidal establishment, there is a constant tide interval between any two places. Whatever may be the time of high water at London, the time at Liverpool is about two and a half hours earlier, and at Cromer six hours earlier and later. This is easily understood, for it merely expresses the fact that in their course around our islands the tidal currents take a certain time to travel from one place to another.

The rate of progress of the tide-wave around our islands may be seen on the chart reproduced in Fig. 298, in which places where high water occurs are connected by **co-tidal**

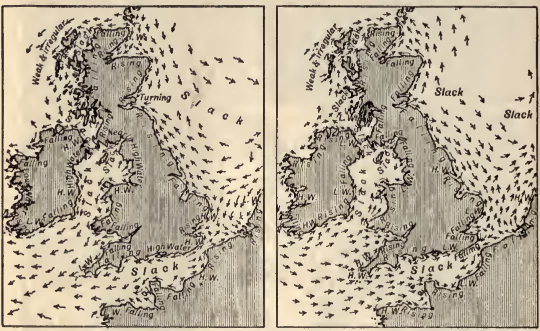


after Berghaus W.&C.

FIG. 298.—Co-tidal lines around the British Isles. The lines show the times at which high water occurs at new and full moon, and also the rate at which the tide-wave progresses around our coasts.

lines. The hours of the clock marked against these lines show the times of high water at new and full moon, so that the lines are really lines of equal tidal establishment. At the mouth of the Thames high tide occurs about twelve o'clock at new and full moon, and that is the time when the moon crosses the meridian there. The flood tide occupies about two hours in coming up from the Nore to London, a distance of about 40 miles; that is to say, it is high water at London Bridge two hours later than at the Nore. Then it takes two hours more for the gradual rise of the water to

Walker and Cockerell.



High Water at Dover. 6 hours after H.W. at Dover.

FIG. 299.—Charts of tidal currents around the British Isles. From the Monthly Pilot Charts of the Meteorological Office.

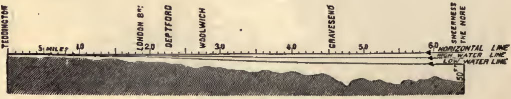


FIG. 300.—Range of tides between Teddington and the Nore.

its highest level, to travel onwards from London to Teddington, though the distance between these two points is less than twenty miles.

As we go up the river, we find the effect of the tide gradually diminishing, until at length it ceases to be felt. At Sheerness the difference between the average height of high and low water, or the **range of the tide,** is about twenty feet, at London Bridge about fifteen feet, while at Teddington Weir (Fig. 301), some nineteen miles above London Bridge, the tidal influence formerly ceased. The tides are not now felt, however, above Richmond, where the first lock occurs.

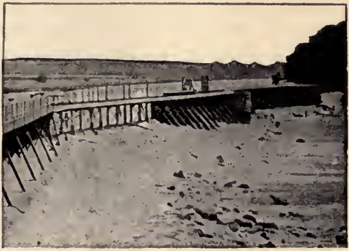


Photo. *H. W. Taunt.*

FIG. 301.—Teddington Weir. Low tide.

Tidal waves.—In the open sea the water is raised by the attraction of the moon, or of the moon and sun combined, and then falls ; so that the true tidal wave represents a mere oscillatory movement up and down. Every particle of water of the oceans, however, partakes of this movement, and in this respect tidal influence differs from that of wind, which only affects water near the surface. In the open ocean the lunar wave rises to a height of about two or two and a half feet, and the solar wave to about one foot, so that the two combined would only produce a tidal wave of about four feet. These are the only true tidal waves, and their velocity in the Atlantic Ocean is about seven hundred miles an hour. The only effect of such waves on a ship is to lift it up and down, but in narrow channels and around complicated coast lines the tidal wave gives rise to a forced wave or current in which the water actually moves backward and forward, as has already been described (see p. 208).

Secular effects of tidal action.—Consideration of the effect of tidal action on the motions of the earth and moon has led Professor G. H. Darwin to results of great interest.[1] The earth rotates under the tide raised by the moon, and the backward pull upon the water acts as a drag upon our spinning globe, tending to decrease the rate of rotation, and therefore to increase the length of the day. Carrying this line of reasoning back through the distant past, Professor Darwin finds that at one time the earth rotated on its axis in less than six hours, so that tidal friction has increased the length of the day to four times its early value. At that epoch the earth and moon rotated together as one body, and the day and the month were of the same length. As the day increased in length, there was a corresponding increase in the distance of the moon from the parent mass and in the length of the month. The number of days in a month increased until a revolution of the moon around the earth occupied nearly twenty-nine rotations, and then decreased to the present time, when the moon's period of revolution is 27⅓ of our days. Looking far into the future, it appears that eventually the earth will turn so slowly on its axis as to take fifty-seven days of the present length to complete one rotation, and the moon's period of revolution will then be of the same length. The final result of the moon's tidal action upon the earth, and the earth's reaction upon the moon, is thus to reduce the day and the month to periods of equal length; and the history of the earth-moon system will be at an end when that great day is reached. But these speculations are not limited to the earth or even to the solar system. Many of the stars which appear as single bodies when viewed through the most powerful telescope are really two or more luminous globes so close together that they cannot be seen separately; and there is substantial reason for believing that they represent stages in the formation of worlds by tidal action. The flow of the tide in a river, or the periodic rise and fall of the waters of the sea, can thus be connected by a continuous line of reasoning with the birth of the moon from the earth, the earth from the sun, and a sun or star from a whirling mass of cosmic matter.

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[1] See *The Tides and Kindred Phenomena in the Solar System.* By Prof. G. H. Darwin. (Murray, 1898.)

Conclusion.—In order to explain the movements of water upon the earth, from the bubbling spring to tidal waves, it has been necessary to refer them to the influence of the sun and moon. In the case of the tides the moon's action predominates, but most of the other effects described are due directly or indirectly to that vast body, more than ninety millions of miles away, around which the earth is constantly circling.

Every river is fed, directly or indirectly, by rain; and the rain is condensed from vapour, which has been raised into the atmosphere by means of solar heat. Without the sun, therefore, there could neither be rain nor rivers; and hence it is not too much to say that the origin of every river is ultimately to be traced to the sun. Rain is dependent for its distribution upon currents in the atmosphere, but these currents are due to disturbances of equilibrium which are brought about by means of solar heat. Without the sun, then, there could be no winds. The currents of the sea engaged attention in another part of our work; but here, again, the sun is the prime mover. Whatever view be taken of the origin of such currents—whether they are due to the immediate action of winds, or to variations of temperature in the water, or to the excess of evaporation in one place over that of another—it is clear that the sun is the real agent in the formation of ocean-currents.

In another chapter attention was directed to the phenomena which are presented by cold, and especially to the formation of glaciers; here, if anywhere, it might have been supposed that the sun certainly had no part to play. Yet it must be remembered that the ice of a glacier is water which has been distilled by the sun's heat, and that the descent of snow in one place connotes the evaporation of water in another locality. Without the sun, therefore, there could be no glaciers.

Considerable attention was given, in several chapters, to the phenomena of life, so far as they bore upon the subject under discussion. But every one knows that heat and light are such necessary conditions for the manifestation of life that the earth would become lifeless if sunshine were withheld. Without the heat which is derived from the sun the temperature of the earth would fall far below the limit at which life can be sustained. All the energy of vital activity is derived directly or indirectly from the energy of the sun, as explained in Chapter XIV. Green plants decompose carbon dioxide and obtain their supply of carbon only under the influence of sunshine; and it has often been remarked that our stores of coal represent so much sunshine of the Carboniferous period. Nor is this a mere wild fancy; for without the sun there would certainly have been no coal.

It has been mentioned that Britain has experienced great changes of climate at different periods of its history; and such changes depend primarily upon our varying relations with the sun. In fact, without the sun a large part of our country could have had no geological history, for many beds of rock are almost exclusively made up of fragments which have been worn from pre-existing land by means of running water; and the flow of water must be connected, directly or indirectly, with the action of the sun.

At the furthest point to which we have pushed our analysis of the causes of the phenomena presented to us, the sun is thus revealed as the grand prime mover in all that circulation of matter which goes on, and has gone on for untold ages, over the surface of the earth; while the fall of a raindrop, the flow of a river, the swing of the tides, prove to be caused by the working of a force which controls the revolution of the earth around the sun, and extends from planet to planet, and from star to star, throughout the universe.

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